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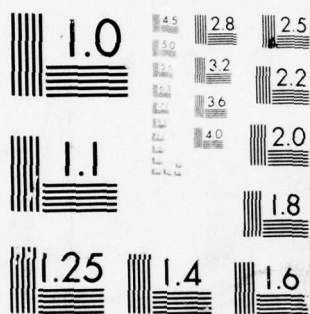
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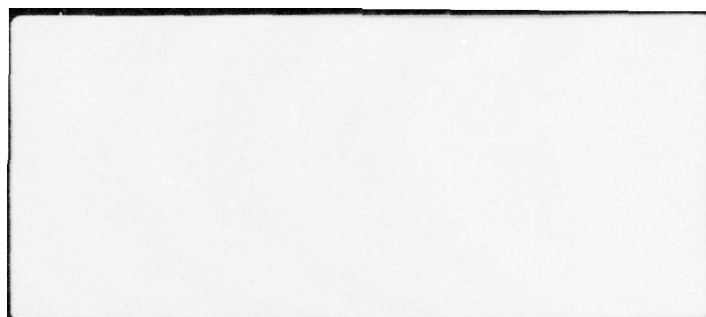


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MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A



Final
9 SUMMARY REPORT

11 26 November 26, 1976

6 COMMUNICATIONS SYSTEMS MODELING STUDY

PREPARED FOR

DIGITAL COMMUNICATIONS CORPORATION

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- DSCS II global beam,
- DSCS II spot beam,
- domestic satellite C-band,
- domestic satellite K-band,
- INTELSAT IV global beam, and
- INTELSAT IV-A regional beam.

A model was prepared for cost calculations as a function of the number of earth stations and voice channels in the system. The following conclusions were drawn:

- The TDMA-PSK-FDMA transmission technique provides only limited connectivity and results in the highest costs. The choice will therefore be between PSK-SCPC and TDMA.*

* The TDMA system considered in this study is simple and provides only variable destination demand assignment. Systems with fully variable demand assignment, where burst lengths are changed in accordance with instantaneous traffic requirements are more complex and expensive.

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- PSK-SCPC leads to the lowest cost system when the channel requirement per earth station is small.
- TDMA will lead to the lowest cost solution when the number of voice channels per earth station is large.
- The break-even capacity between PSK-SCPC and TDMA is about 50 to 60 channels per earth station. It varies slightly with the specific satellite transponder that is used and it depends on the number of earth stations in the system as shown in Table S-1, where

n = number of channels in the system

m = number of earth stations in the system.

Table S-1
Break-even Formulas

Satellite Type	Break-even Channel Capacity (Channel Units Per System)
DSCS II, Global Beam	$n = 11 + 50 m$
DSCS II, Spot Beam	$n = 37 + 44 m$
Domestic, C-band	$n = 37 + 42 m$
Domestic, K-band	$n = 37 + 49 m$
INTELSAT IV, Global Beam	$n = 16 + 79 m$
INTELSAT IV-A, Regional	$n = 32 + 43 m$
Average	$n = 30 + 50 m$

At system loads that are different from break-even capacity, one of the two systems will be less expensive to

operate than the other. The formulas for calculation of the cost difference are shown in Table S-2, where

A' = annual systems costs for TDMA systems
A = annual systems costs for PSK-SCPC systems.

It was found that the cost differences for the two global beam transponders are similar, and that the cost differences for the four spot beam transponders as a group are similar. It is therefore reasonable to calculate cost differences for average global beam and average spot beam transponders.

Table S-2
Cost Difference Formulas
Annual Cost Difference in \$1000

Transponder Type	Cost Difference: A' - A TDMA Minus SCPC System Costs
DSCS II Global Beam	$A' - A = 52 + 230 m - 4.6 n$
INTELSAT IV, Global Beam	$A' - A = 52 + 261 m - 3.3 n$
Average Global Beam Transponder	$A' - A = 52 + 246 m - 4.0 n$
DSCS II Spot Beam	$A' - A = 52 + 62 m - 1.4 n$
Domestic, L-Band	$A' - A = 52 + 60 m - 1.4 n$
Domestic, K-Band	$A' - A = 52 + 69 m - 1.4 n$
INTELSAT IV-A Regional	$A' - A = 52 + 69 m - 1.6 n$
Average Spot Beam Transponder	$A' - A = 52 + 65 m - 1.5 n$

System cost differences based on the formulas for the average global beam transponder and the average spot beam transponder are plotted in Figures S-1 and S-2. These costs include antennas, RF equipment, baseband equipment,

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Systems were configured for the following three traffic models:

Traffic Model	Low Capacity	Medium Capacity	High Capacity
Number of earth stations	26	10	211
Number of channel units	80	219	1100
Traffic intensity in Erlangs	19	133	492
Space segment channels	29	152	518

Normalized costs for these three models are shown in Table S-3. PSK-SCPC is the lowest cost solution for all combinations of satellite transponder and traffic model. TDMA is the second cheapest solution.

A sensitivity study was performed to determine the effect of changing earth station cost assumptions on the result. Earth station equipment costs were doubled as would be the case if Mil Spec rather than commercial equipment was used. The break-even capacities increased slightly as the result of this change.

The use of fully variable demand assignment results in higher system costs than the use of variable destination demand assignment.

It was concluded that TDMA is generally the best solution when the average traffic per earth station is over 50 to 60 channels and that PSK-SCPC is the best solution when the average traffic per earth station is less than that.

Table S-3
Normalized Systems Cost Comparison
Annual Costs, PSK-SCPC = 1.00

Traffic Model	Low Capacity	Medium Capacity	High Capacity	Average
PSK - SCPC	1.00	1.00	1.00	1.00
TDM-PSK-FDMA	3.43	1.98	4.10	3.03
TDMA - maximum bit rate	3.35	1.45	2.88	2.41
TDMA-FDMA	2.76	1.83		2.25
TDMA - reduced bit rate	3.14			3.14

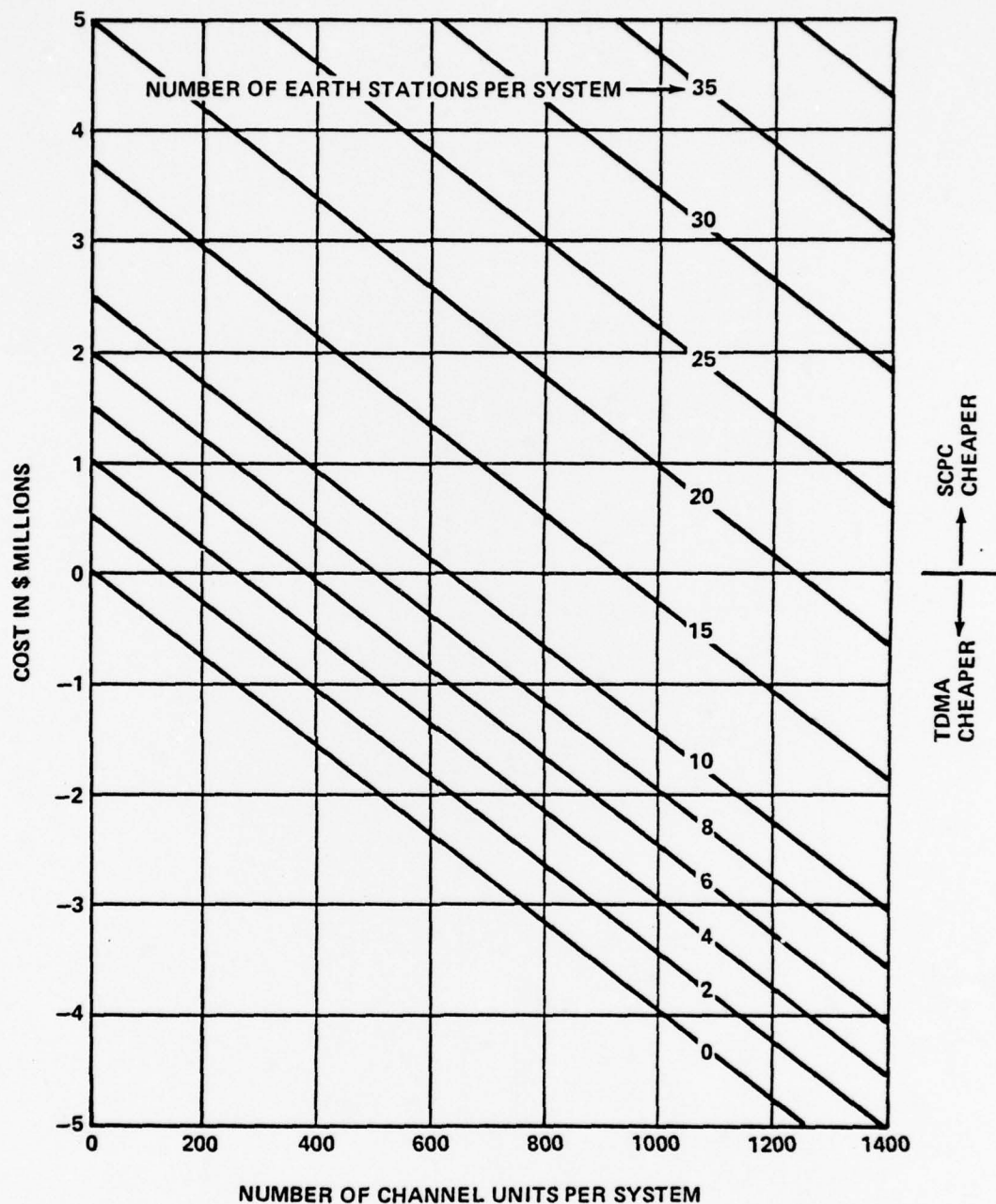


FIGURE S-1

ANNUAL COST DIFFERENCE IN \$ MILLION
TDMA SYSTEM COSTS MINUS SCPC
SYSTEM COSTS FOR OPERATION WITH
A TYPICAL GLOBAL BEAM TRANSPONDER

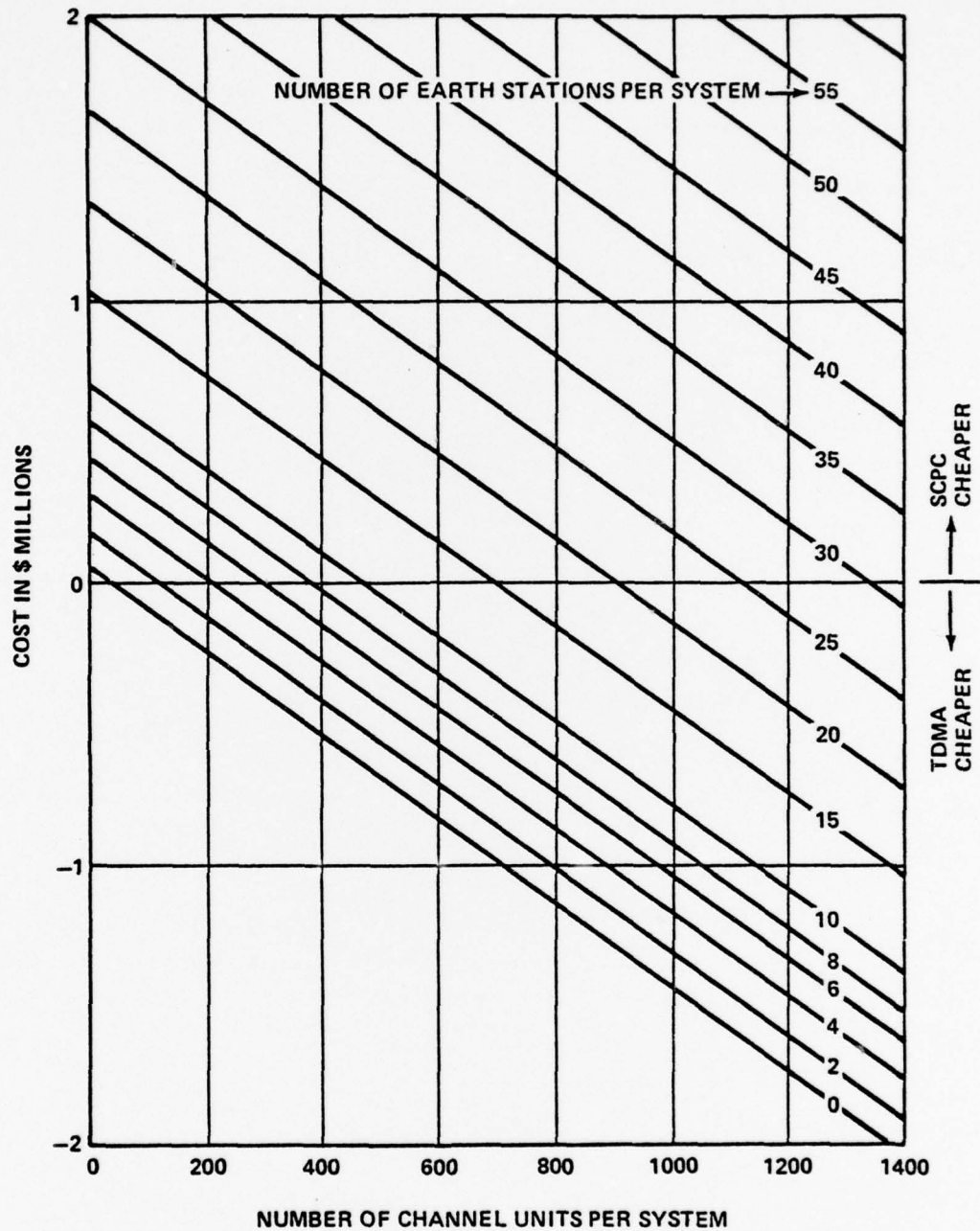


FIGURE S-2
ANNUAL COST DIFFERENCE IN \$ MILLION
TDMA SYSTEM COSTS MINUS SCPC
SYSTEM COSTS FOR OPERATION WITH
A TYPICAL SPOT BEAM TRANSPONDER

FINAL REPORT

November 26, 1976

COMMUNICATIONS SYSTEMS MODELING STUDY

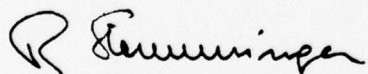
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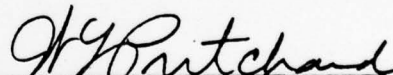
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EXECUTIVE SUMMARY

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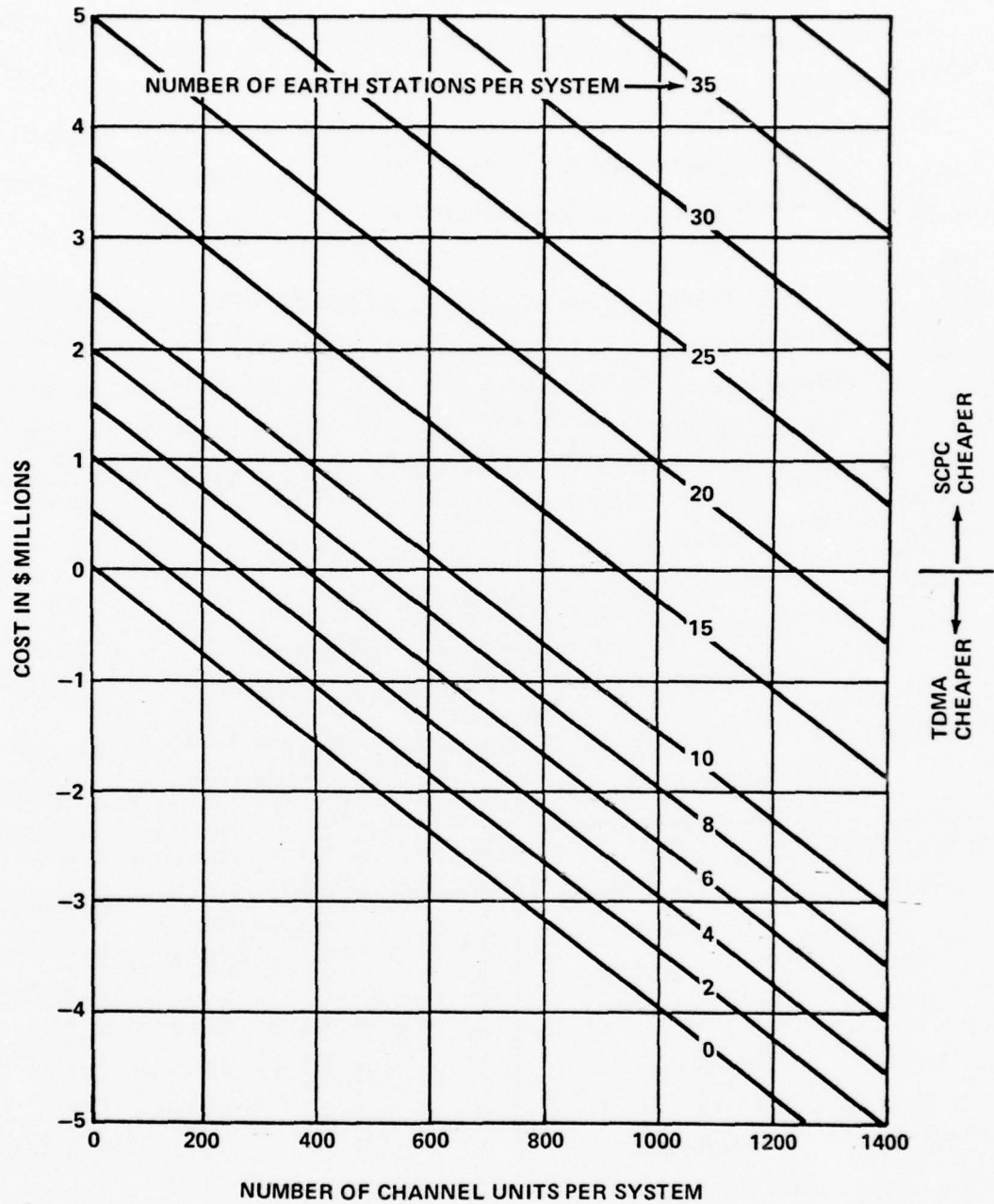


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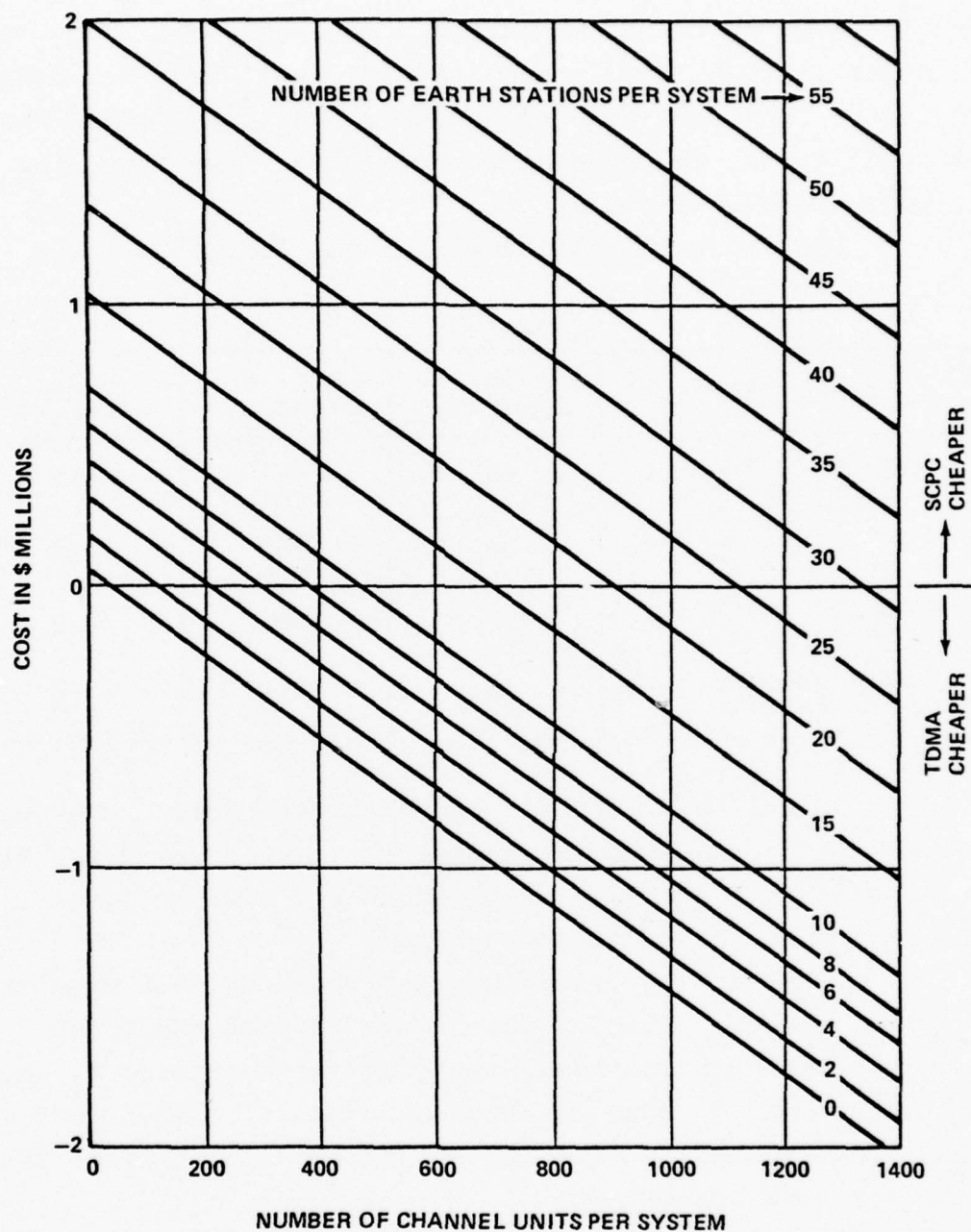


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TDMA-FDMA	2.76	1.83		2.25
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Section 1
INTRODUCTION

This Communications Systems Modeling Study was prepared for Digital Communications Corporation by Satellite Systems Engineering, Inc., under Purchase Order No. 761 830, dated July 26, 1976.

The study developed and compared systems costs for three modulation/access techniques and three traffic models:

PSK-SCPC. Phase shift keyed single channel per carrier transmission with voice activation. Fully variable demand assignment is provided.

TDM-PSK-FDMA. Transmission of multiple digital carriers per transponder. Each earth station transmits all its traffic on a single carrier and receives a separate carrier for each link over which it wishes to communicate. Demand assignment is available within each carrier.

TDMA. Time division multiple access. Each station transmits a burst with a number of bits corresponding to the total number of channels of the station. Variable destination demand assignment is available within the burst, but the burst lengths are not changed in accordance with demand.

In all cases, the voice channels are encoded with 16 kb/s variable slope delta modulation. Whether or not encrypting is used has no impact on the results of this study.

Three traffic models were used in the study: A low-capacity, a medium capacity and a high-capacity model ranging from 80 to 1100 channels.

Transmission over six different satellite transponders has been studied:

- DSCS II, Global beam transponder
- DSCS II, Spot beam transponder
- Domestic satellite, C-band transponder
- Domestic satellite, K-band transponder
- INTELSAT IV, Global beam transponder
- INTELSAT IV-A, Regional coverage transponder.

In order to perform the economic comparison, space segment and ground segment costs have been estimated and a cost model was generated. The optimum earth station G/T was determined for each modulation/access technique and each transponder type. Annual system costs were calculated for each case. A general systems cost model was also developed, in order to be able to make system cost comparisons for other traffic models than those assumed in the study.

Based on this work, it was possible to clearly define the conditions under which a given modulation technique will be preferable over the others. A sensitivity study was also performed in order to check the sensitivity of the conclusions to changes in the assumptions.

Section 2
SYSTEM ASSUMPTIONS

2.1 TRAFFIC MODELS

For the purpose of this study, three traffic models have been assumed: a medium capacity, a low capacity and a high capacity model. It is assumed that many typical user applications will fall within the range of traffic encompassed by these models.

2.1.1 Medium Capacity Traffic Model

This traffic model was extracted from Technical Note No. 39-75 of the Defense Communications Engineering Center: Design of a Demand Assignment Satellite Network, by Dr. Nicholas Kyriakopoulos, December 1975. The model is based on actual switched traffic in Europe and is shown in Table 2-1. The model shows traffic among 10 locations, coded A through L. The traffic for each link as well as the total traffic for each location is expressed in Erlangs. The equivalent number of channels shown for each location is based on a grade of service of 1 in 100 and on the Erlang B equation. The channels are demand-assigned since they are based on the total traffic for each location, regardless of the destination.

Table 2-1
Medium Capacity Traffic Model
Busy Hour Traffic in Erlangs

To From	A	B	C	D	E	F	G	H	K	L	Traffic Offered to Satellite	Required DA Channels
A		1.10	2.70	.15	.30	1.05	.35	.45	1.10	.10	7.30	14
B	.60		4.85	.30	1.05	4.30	.60	.85	.55	.80	13.90	23
C	1.85	2.65		.95	1.30	4.25	1.30	1.90	.35	1.30	15.85	25
D	.15	.60	3.20		1.70	2.90	6.00	.35	1.05	.20	16.15	26
E	.30	.35	2.50	1.30		2.00	2.25	1.10	1.10	1.10	12.00	20
F	1.25	5.30	7.00	1.45	2.00		2.60	1.30	.70	1.00	22.60	33
G	.25	.35	5.45	5.90	1.30	2.90		.30	.40	.35	17.20	27
H	.60	.60	3.70	.20	.95	1.50	.35		1.00	.10	9.00	17
K	2.40	.20	1.05	.60	1.00	.50	.30	1.10		--	7.15	14
L	.60	2.00	4.55	.25	1.00	2.50	.80	.20	--		11.90	20
Traffic Received	8.00	13.15	35.00	11.10	10.00	21.90	14.55	7.55	6.25	4.95		
Receive Channels Required	15	22	47	19	19	32	24	15	13	11		219 217

2.1.2 Low Capacity Traffic Model

For this model, the channel requirements shown in Table 2-2 have been assumed.

Table 2-2
Low Capacity Traffic Model

Location Category	Number of Locations	Channels Per Location	Total Number of Channels
A	1	20	20
B	5	6	30
C	10	2	20
D	10	1	10
Total	26		80

All channels are demand assigned.

2.1.3 High Capacity Traffic Model

For this model, the channel requirements shown in Table 2-3 have been assumed.

Table 2-3
High Capacity Traffic Model

Location Category	Number of Locations	Channels Per Location	Total Number of Channels
A	1	200	200
B	10	20	200
C	100	6	600
D	100	1	100
Total	211		1100

All channels are demand assigned.

2.2 SPACE SEGMENT

In generating systems configurations, it will be assumed that the traffic postulated in the models in Section 2.1 may be transmitted through any of the following satellites:

DSCS Phase II satellites

- Global or spot beam transponders

INTELSAT satellites

- INTELSAT IV, global beam
- INTELSAT IV-A, regional coverage beam

Domestic satellites

- Typical U.S. domestic satellite with characteristics similar to Westar
- Future domestic satellite with capability at K-band.

A brief description of the transponder characteristics of these satellites is given below.

2.2.1 DSCS Phase II Satellites

The DSCS Phase II satellites are spin-stabilized at approximately 60 rpm and have two steerable narrow beam antennas with a beamwidth of 2.5 degrees each, and a global beam antenna with a beamwidth of 18 degrees. The antennas are mounted on a despun platform.

The transponders are cross-strapped to allow reception by one antenna and transmission by the other. Figure 2-1 shows the transponder frequency plan. Four transmission channels are provided with the characteristics shown in Table 2-4.

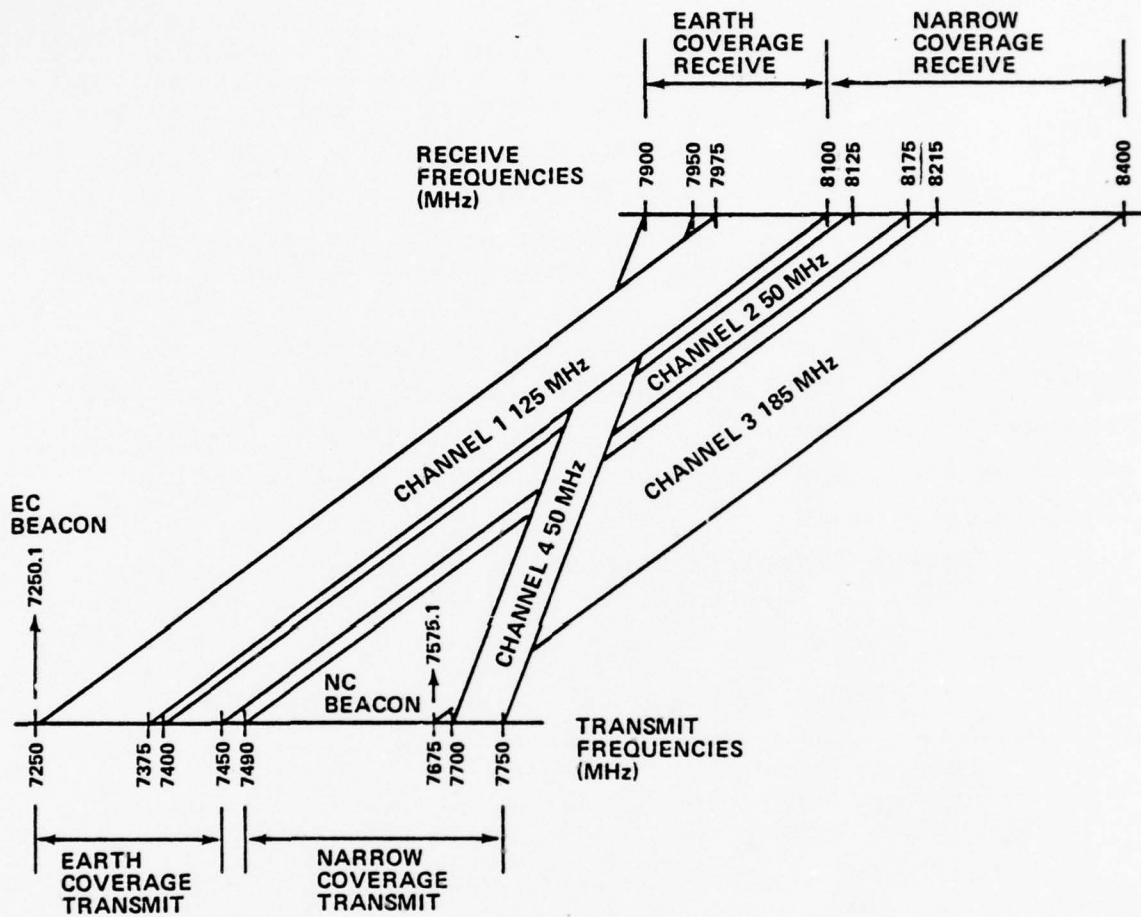


FIGURE 2-1

DSCS SATELLITE, PHASE II TRANSPONDER FREQUENCY PLAN

Table 2-4
DSCS II Channel Bandwidths

Channel No.	Bandwidth in MHz	Transmit Antenna	Receive Antenna
1	125	Earth Coverage	Earth Coverage
2	50	Earth Coverage	Spot Beam
3	185	Spot Beam	Spot Beam
4	50	Spot Beam	Earth Coverage

A single 20 watt TWT is associated with the global beam transmit antenna and another 20 watt TWT with the spot beam antennas. Thus, if more than 1 transponder is used in any given beam, the associated TWT cannot operate in the single carrier mode.

Transponder characteristics are shown in Table 2-5.

Table 2-5
DSCS II Transponder Characteristics

Antenna Beam	Global	Spot
Beamwidth, degrees	18	2.5
Antenna gain at 8 GHz	16.8 dB	33 dB
Transmit EIRP, single carrier saturation at beam center	28 dBW	43 dBW
Receive G/T, at beam center	-19 dB/K	-3 dB/K
Transponder gain	commandable	commandable

2.2.2 INTELSAT Satellites

INTELSAT IV global beam transponders and INTELSAT IV-A regional transponders are available for lease from INTELSAT for domestic communications. The transponder characteristics are shown in Table 2-6.

Table 2-6
INTELSAT Transponder Characteristics

Satellite Type	INTELSAT IV	INTELSAT IV-A
Antenna coverage	Global	Regional
Transmit EIRP, single carrier saturation, minimum over coverage	22 dBW	29 dBW
Single carrier saturation flux density, at beam edge	-73 dBW/m ²	-75 dBW/m ²
Receive G/T, minimum over coverage area	-18 dB/K	-11.6 dB/K

In the Atlantic area, the regional INTELSAT IV-A antenna beams cover an area bounded by the following INTELSAT stations:

Northwest beam	Mill Village, Canada
	Mexico
	West Indies
	Ecuador
Southwest beam	Peru
	Brazil
	Argentina
Northeast beam	Sweden
	Senegal
	Sudan

Southeast beam	Ivory Coast
	Ethiopia
	Mozambique

2.2.3 Domestic Satellites

Transponders of typical domestic satellites will be included in the study. Such transponders use 5 watt TWTs and have a bandwidth of 36 MHz at C-band. With shaped beam coverage for CONUS and Alaska an EIRP of 33 dBW is achieved. The domestic satellite specified by Brazil has a different antenna beam shape, but provides the same EIRP. These transponders operate at C-band.

U.S. domestic satellites with K-band capability have not yet been procured; therefore, the K-band transponder characteristics are not yet firm.

Table 2-7
Domestic Satellite Transponder Characteristics

Frequency Band	C-Band	K-Band
Antenna coverage	CONUS and Alaska	CONUS
EIRP, single carrier saturation, minimum over coverage area	33 dBW	38 dBW
Bandwidth	36 MHz	54 MHz
Receive G/T	-6 dB/K	-6 dB/K
Saturation flux density	-83 dBW/m ²	-83 dBW/m ²

2.3 GROUND SEGMENT CHARACTERISTICS

For the purpose of this study, the following ground segment characteristics have been assumed:

2.3.1 Existing Terminals

Table 2-8
Existing Terminals

Terminal	Antenna Diameter (feet)	G/T (dB/K)	EIRP (dBW)	TX Power (kW)
AN/WSC-2	4	12	67.8	
AN/MS-85	8	18		0.5
AN/TSC-54	18	26.5		5
AN/MS-46	40	34		10
AN/FSC-78	60	39		8

INTELSAT Standard A Terminals 100 feet dia., 40.7 dB/K G/T.
INTELSAT Standard B Terminals 32 feet dia., 30.7 dB/K G/T.
U.S. Domestic Terminal, similar to INTELSAT Standard B.

2.3.2 New Terminals

New terminals will be configured to meet systems requirements at minimum cost for each application. Smallest permissible size will be based on INTELSAT requirements and FCC requirements for limitations on adjacent satellite interference.

2.4 SIGNALING REQUIREMENTS

In the basic system design, it will be assumed that there are no signaling requirements that would be affected by the satellite transmission delay. Signaling information can be transmitted equally well with any of the three modulation/access techniques under study. For these reasons, signaling requirements need not be considered in this comparative study.

Section 3
BASIC SYSTEMS CONFIGURATIONS

In this section, basic systems configurations have been developed for the three modulation/access techniques under investigation:

- a PSK-SCPC System
- a TDM-PSK-FDMA System
- a TDM-PSK-TDMA System.

3.1 DEMAND ASSIGNMENT VERSUS PRE-ASSIGNMENT

This paragraph presents an analysis of the traffic models regarding the number of channels that are required with demand assignment and with pre-assignment of channels.

3.1.1 Medium Capacity Traffic Model

The traffic model shown in Table 2-1 shows the Erlang load for each link and the number of demand-assigned channels that are required for each location to satisfy the traffic with a grade of service of 1 in 100, based on the Erlang B equation.

The Erlang B equation is used to calculate the probability of call blockage. It assumes an infinite source of callers and also assumes that lost calls are cleared. It has been recommended for use by the CCITT.

$$P = \frac{\frac{y^n}{n!}}{\sum_{o}^n \frac{y^n}{n!}}$$

where:

P = probability of blocking
n = number of channels
y = traffic load in Erlangs.

For convenience, the Erlang B tables have been used in this study and a grade of service or probability of blocking of 0.01 was used throughout. Figure 3-1 is a graphic presentation of Erlang load versus number of channels for grades of service 1 in 20, 1 in 100, and 1 in 1000.

Table 3-1 shows the number of channels required for the medium capacity traffic model, if pre-assigned channels are used. The traffic concentration factor with demand assignment is approximately 2.1 for this model.

Total pre-assigned one-way channels	467
Total demand assigned one-way channel units	219
Total Erlang load in the system	133
Total satellite channels required	152

The total demand-assigned one-way channel units are based on a probability of blocking of 0.01 at any earth station. Since a circuit requires a channel unit at two earth stations, the end to end probability of blockage is approximately 0.02. If the satellite is capacity limited to 152 channels, it also introduces a separate probability of blocking of 0.01. Thus the probability of blocking for the overall link is approximately 0.03.

If an overall probability of blocking of 0.01 is required, it is necessary to design each earth terminal and the satellite link for an individual probability of blocking of 1 in 300.

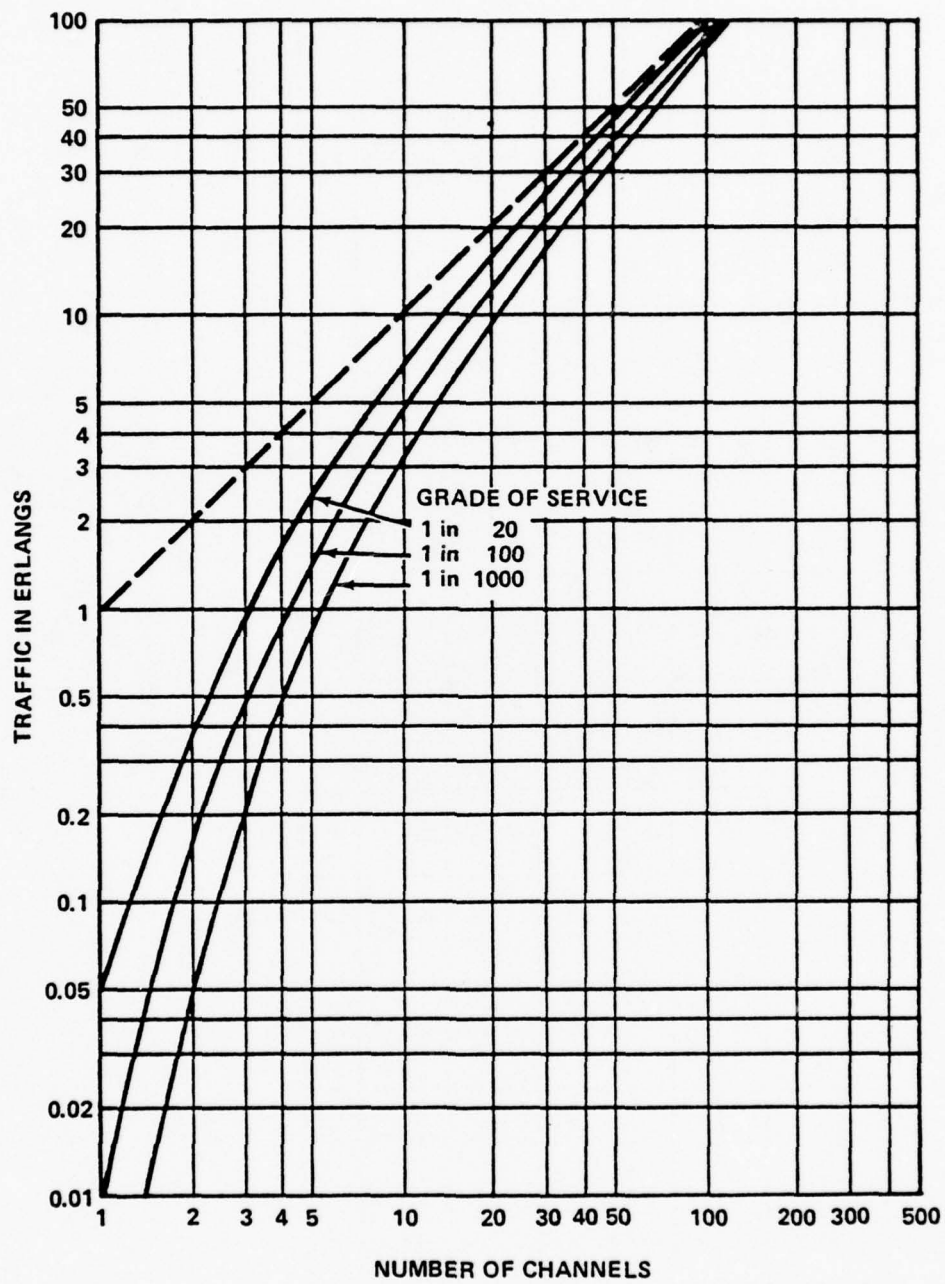


FIGURE 3-1
ERLANG LOAD VERSUS NUMBER OF CHANNELS

3.1.2 Low-Capacity Traffic Model

To determine the impact of demand-assignment versus pre-assignment, assumptions must be made regarding the required connectivity and traffic distribution. It was assumed that all stations must be interconnected to each other, except that stations category C are only connected to stations A and B, and stations category D are connected only to station A. The station interconnect matrix is shown below.

	A	B	C	D
A		X	X	X
B	X	X	X	
C	X	X		
D	X			

Based on this interconnect matrix, the traffic distribution shown in Table 3-2 was developed; traffic is shown in Erlangs.

Table 3-2
Traffic Distribution for Low Capacity Model

Link	Traffic Per Link	Traffic Per Originating Station	Total Traffic Per Category
A to B	1.41	7.05	A 8.15
A to C	0.10	1.0	
A to D	0.01	<u>0.1</u>	
		8.15	
B to A	1.41	1.41	B 9.55
B to B	0.1	0.4	
B to C	0.01	<u>0.1</u>	
		1.91	
C to A	0.10	0.10	B 1.50
C to B	0.01	<u>0.05</u>	
		0.15	
D to A	0.01	0.01	D 0.10
Total System Traffic			19.3

With this traffic distribution station A would require only 16 channel units. In actual practice, the traffic load on the links between stations D to A and C to A could be higher, thus justifying the 20 channels provided at station A. The equivalent number of pre-assigned channels to satisfy the traffic distribution of Table 3-2 is shown in Table 3-3.

Table 3-3
Number of Pre-Assigned Channels for
Low Capacity Traffic Model

Link	Channels Per Link	Channels Per Station	Total Channels Per Category
A to B	5	25	A 55
A to C	2	20	
A to D	1	<u>10</u>	
		55	
B to A	5	5	B 115
B to B	2	8	
B to C	1	<u>10</u>	
		23	
C to A	2	2	C 70
C to B	1	<u>5</u>	
		7	
D to A	1	1	D 10
Total Channels in the System			250

The comparison between the pre-assigned and demand-assigned channels for the low capacity traffic model is shown below:

Total pre-assigned channels	250.0
Total demand-assigned channel	
units at all earth stations	80.0
Total system Erlang load	19.3
Total satellite channels	
needed with demand assignment	29.0

3.1.3 Conclusion

Analysis of the medium capacity model shows that the channel concentration factor¹ as the result of demand-assignment is better than 2 to 1. For the low capacity model, the channel unit concentration factor² is more than 3 to 1, even though the pre-assigned model does not provide full interconnectivity. The channel concentration factor is approximately 8. For the high capacity model, the channel concentration factor would be even higher and more severe limitations in lack of interconnectivity would have to be accepted if traffic were pre-assigned.

For these reasons, it is concluded that demand-assignment is essential for all the traffic models under study and demand-assignment will therefore be used in all systems models.

3.2 CARRIER-TO-NOISE DENSITY REQUIREMENT

In all cases, the voice channels are digitally encoded at bit rates of 16 kb/s or 32 kb/s. In the former case, 2-phase PSK is used, resulting in a noise bandwidth of approximately 20 kHz. In the latter case, 4-phase PSK is used with the same noise bandwidth. All calculations have been performed for the 16 kb/s system; transmission of the 32 kb/s system requires 3 dB higher C/N_o .

$$\frac{C}{N} = \frac{E_b}{N_o} + 10 \log \frac{R}{BW} + M_s$$

$$\frac{C}{N_o} = \frac{C}{N} + 10 \log BW$$

¹ - Channel Concentration refers to satellite channels.

² - Channel Unit Concentration refers to terminal hardware.

where

$\frac{C}{N}$ = total carrier-to-noise ratio at the normal operating point

$\frac{E_b}{N_o}$ = energy per bit-to-noise density ratio at threshold. For the delta modulation system assumed in this study threshold occurs at $BER = 10^{-2}$ which corresponds to $E_b/N_o = 6$ dB.

R = bit rate, 16 or 32 kb/s

BW = IF bandwidth per channel, approximately 20 kHz

M_s = system margin, assumed to be 5 dB at C-band.

This results in normal operation at a BER of better than 10^{-4} . Such margin is required for all system variations such as antenna pointing errors, power level variations, rain attenuation, etc.

$\frac{C}{N_o}$ = carrier-to-noise density ratio in dB Hz.

For 2-phase operation

$$\frac{C}{N} = 6 + 10 \log \frac{16}{20} + 5 = 10 \text{ dB}$$

and

$$\frac{C}{N_o} = 10 + 10 \log 20,000 = 53 \text{ dB Hz.}$$

For 4-phase operation

$$\frac{C}{N} = 6 + 10 \log \frac{32}{20} + 5 = 13 \text{ dB}$$

and

$$\frac{C}{N_o} = 13 + 43 = 56 \text{ dB Hz}$$

3.3 PSK-SCPC SYSTEM

3.3.1 Link Calculations

In this single channel per carrier system, demand assignment is accomplished by central control, using a separate common control channel. Through this system, full flexibility is accomplished; any station can be interconnected on demand with any other station in the system. Rate 1/2 coding can be employed for the common control channel to achieve low bit error rates. Therefore, in the basic link calculation, only the performance of the voice channels will be determined.

Satellite power is conserved by the provision of a voice operated switch. The voice activity statistics depend on the number of channels in the system. McClure [1] has calculated the relationship shown in Table 3-4.

Table 3-4
Voice Activity Statistics Versus Number of Channels

Number of Channels in the System	Voice Activity Ratio at Any Given Moment Not to Be Exceeded for:	
	90% of the Time	99% of the Time
12	0.60	0.75
20	0.55	0.66
50	0.48	0.55
100	0.44	0.50
800	0.40	0.42

[1] R. B. McClure, Comsat Technical Memorandum CL-12-71, March 31, 1971, Link Power Budget Analysis for SPADE and Single Channel PCM/PSK.

The long-term average voice activity ratio is 0.40. This ratio will be used in the satellite capacity calculations regardless of the number of channels in the system for the following reasons:

- (a) The statistics in Table 3-4 assume that the voice switching on all channels in the system is uncorrelated. In actual fact, there is a correlation between each pair of voice channels forming a circuit. In a normal conversation, while one party talks, the other listens. Thus, even for only 2 channels in the system, the voice activity factor is less than 0.5, except for the small percentage of time when both parties talk simultaneously.
- (b) An adequate system margin has been allowed to absorb temporary peak power requirements when the voice activity ratio of 0.4 is exceeded.

Total carrier-to-noise ratio is calculated with the following equation, using numerical values:

$$\left(\frac{C}{N}\right)_T = \frac{1}{\frac{1}{\left(\frac{C}{N}\right)_u} + \frac{1}{\left(\frac{C}{N}\right)_D} + \frac{1}{\left(\frac{C}{N}\right)_I}}$$

where:

$\left(\frac{C}{N}\right)_T$ = total carrier-to-noise ratio in the receiving bandwidth

$\left(\frac{C}{N}\right)_u$ = up-link carrier-to-noise ratio

$\left(\frac{C}{N}\right)_D$ = down-link carrier-to-noise ratio

$\left(\frac{C}{N}\right)_I$ = carrier-to-intermodulation noise ratio.

Up-link carrier-to-noise ratio is calculated as follows; all numbers are expressed in dB.

$$\left(\frac{C}{N}\right)_u = W_s - G_m^2 - BO_I - X + \left(\frac{G}{T}\right)_s - k - 10 \log BW$$

where:

W_s = satellite saturation flux density in dBW/m²
 G_m^2 = gain of a square meter relative to isotropic

$$G_m^2 = 10 \log \frac{4\pi}{\eta^2}$$

where η = wavelength in meters.

At 6 GHz, $G_m^2 = 37$ dB;
 at 7.5 GHz, $G_m^2 = 39$ dB.

BO_I = input back-off, dB
 $X = 10 \log N$

N = number of active channels per transponder.
 With a voice activity of 0.4 the total number of channels per transponder is 2.5 times N .

$\left(\frac{G}{T}\right)_s$ = satellite G/T

K = Boltzmann's constant, -228.6 dB
 BW = receive noise bandwidth per channel, 20 kHz.

Down-link carrier-to-noise ratio is calculated as follows; again all numbers are expressed in dB.

$$\left(\frac{C}{N}\right)_D = \text{EIRP}_S - \text{BO}_O - X - \text{PL}_D + \left(\frac{G}{T}\right)_E - k - 10 \log BW$$

where:

EIRP_S = satellite EIRP, single carrier saturation

BO_O = output back-off, dB

PL_D = down-link pathloss. For the frequency of 4 GHz, a pathloss of 196.2 dB was used, which corresponds to an elevation angle of 30 degrees.

$\left(\frac{G}{T}\right)_E$ = earth station G/T.

The carrier-to-intermodulation noise ratio can be determined from Figure 3-2. The curves in this figure were derived from Reference [1]. With voice operated switching, the carrier-to-intermodulation noise ratio is 4 dB higher than without voice switching.

The next step in the channel capacity calculations is the determination of the optimum operating point for a given satellite-earth station combination. Figure 3-3 shows the carrier-to-noise ratios for the example of a domestic C-band transponder and an earth station with a G/T of 32 dB/K.

The down-link carrier-to-noise ratio can be calculated for single carrier saturation. The multi-carrier saturation C/N is 1.5 dB lower. The relationship of input versus output back-off for single and multi-carrier transmission is shown on Figure 3-4 as single and multi-carrier C/N ratios.

The optimum operating point corresponding to the highest carrier-to-noise ratio is at 11 dB input back-off. However, the system provides satisfactory performance over

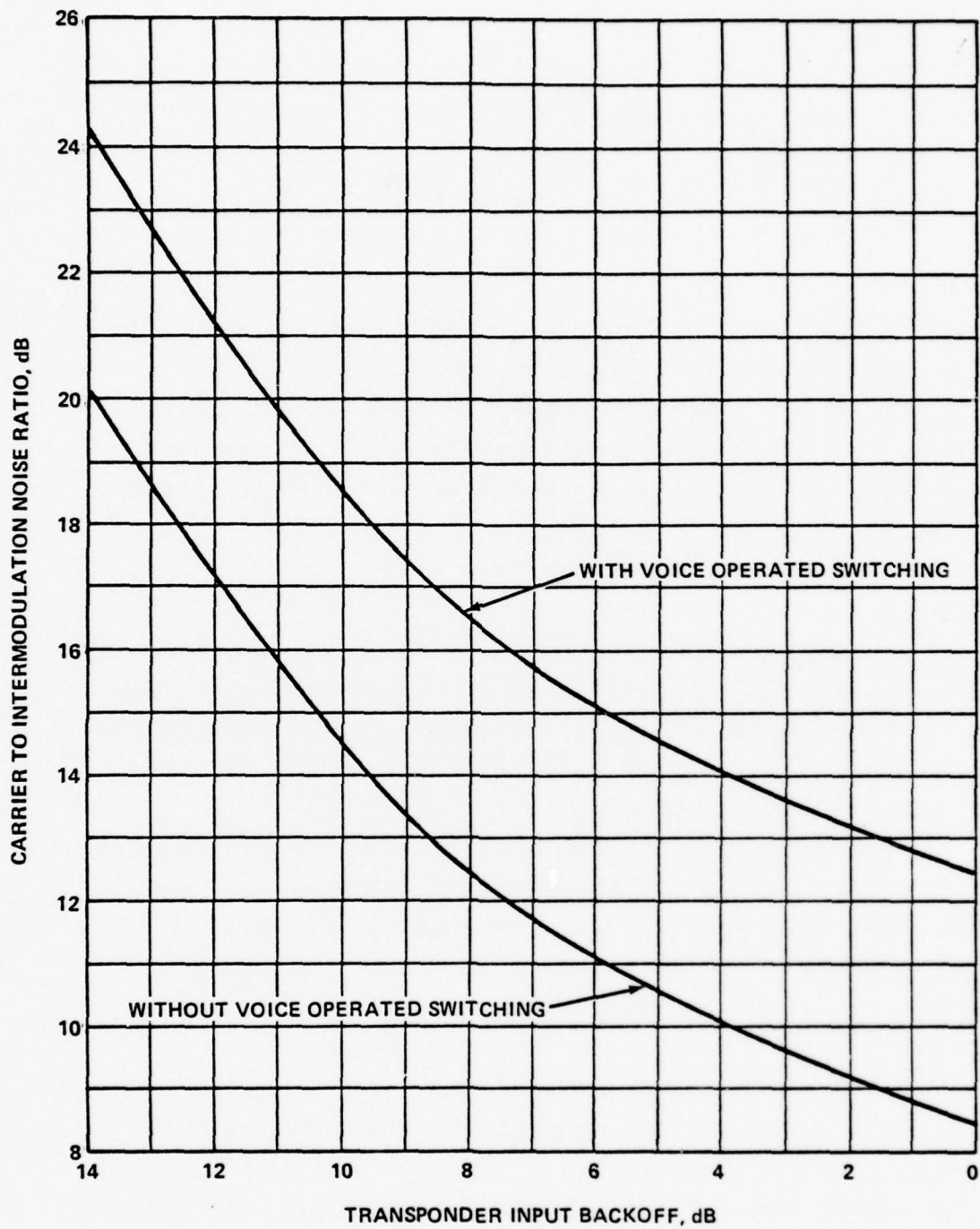


FIGURE 3-2
CARRIER TO INTERMODULATION NOISE
RATIO FOR SCPC TRANSMISSION

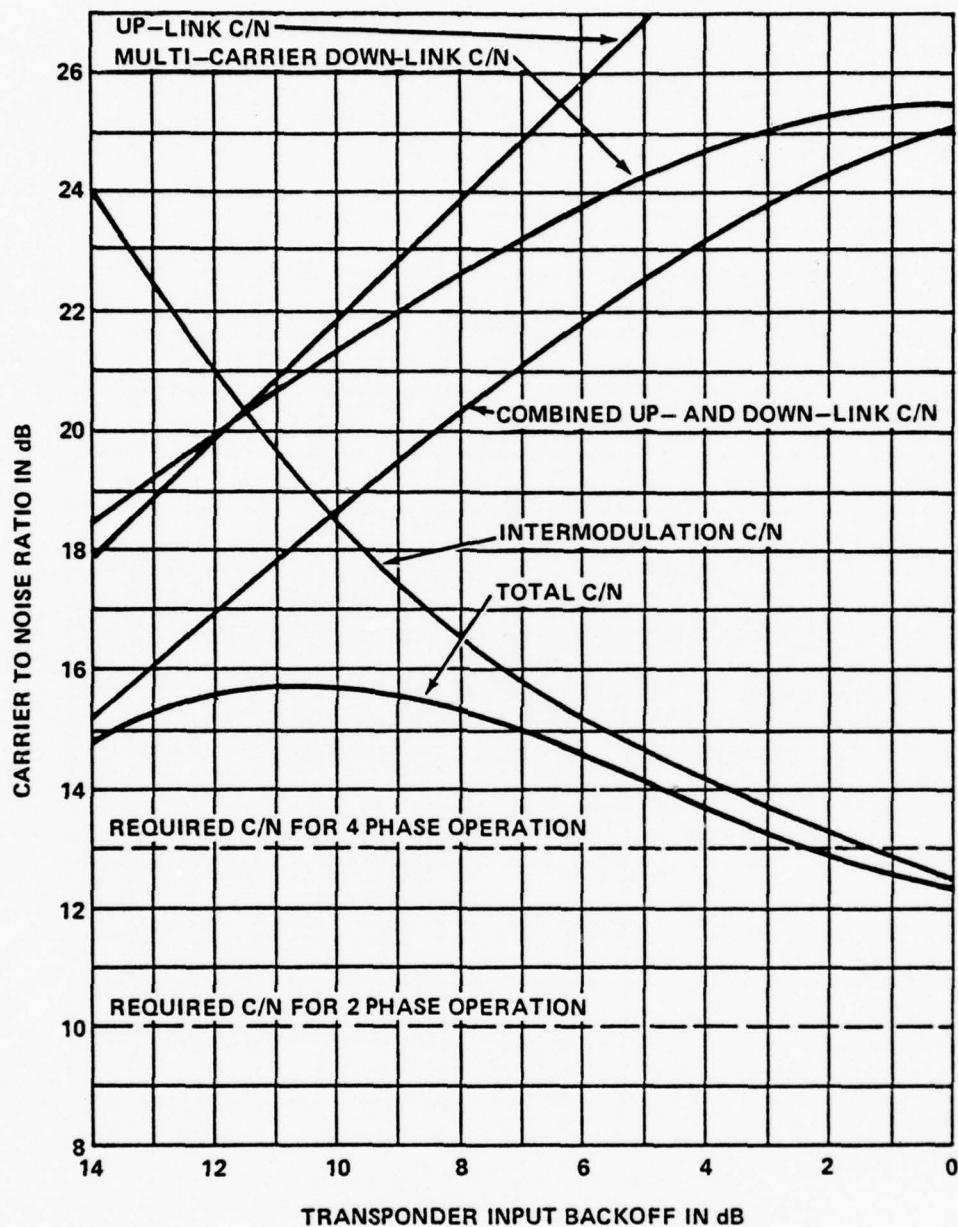


FIGURE 3-3

OPTIMUM OPERATING POINT
FOR SCPC TRANSMISSION
EIRP = 33 dBW, G/T = 32 dB/K

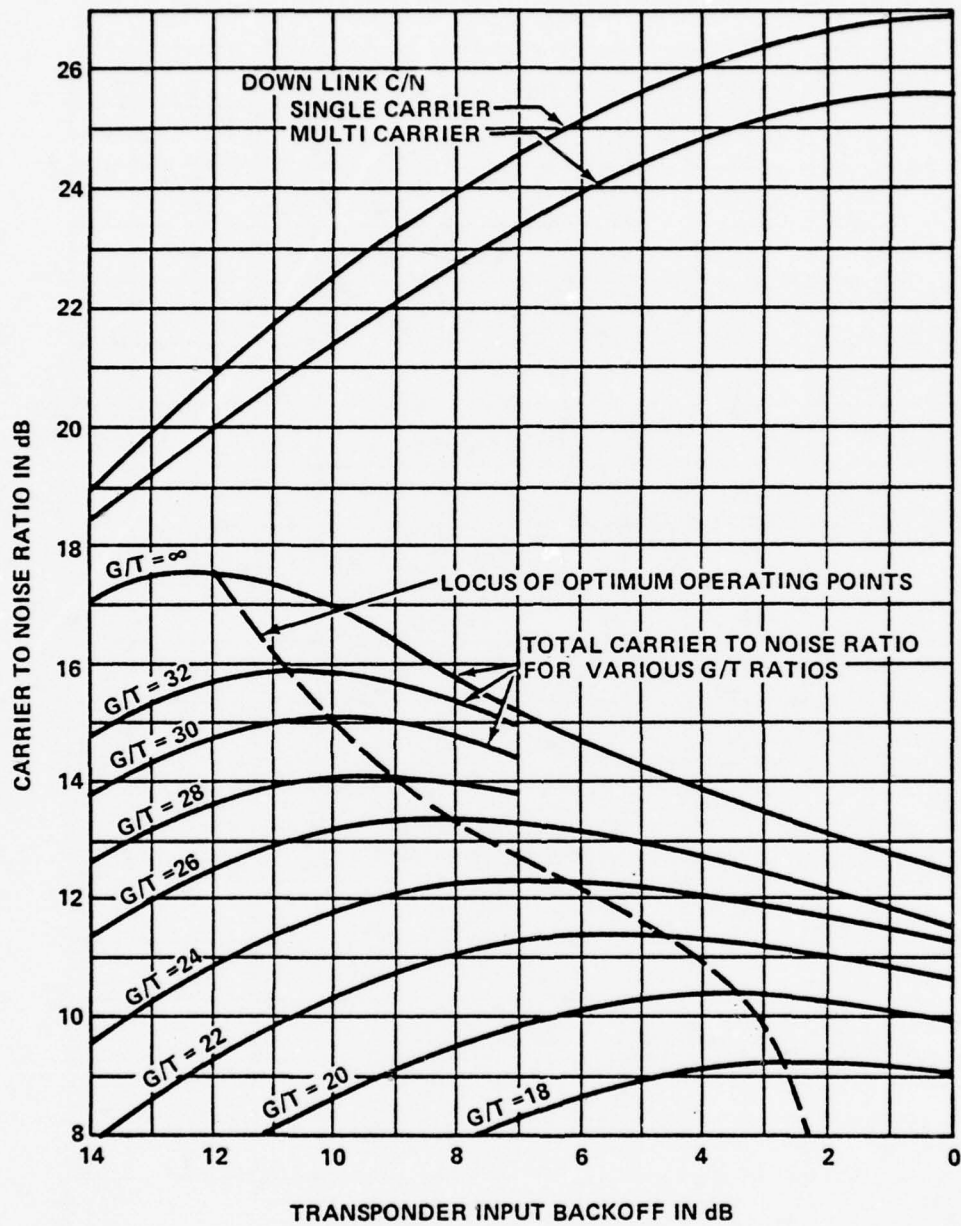


FIGURE 3-4

OPTIMUM OPERATING POINTS FOR SCPC TRANSMISSION
EIRP = 33 dBW, VARIOUS G/T RATIOS

a wide range of back-offs, both for 2-phase and 4-phase operation, indicating that lower earth station G/T ratios are adequate.

Figure 3-4 shows the optimum operating points for SCPC transmission over a range of G/T ratios. With a domestic satellite with 36 MHz bandwidth and 33 dBW EIRP, an earth station G/T of 18 to 20 dB/K is the lowest G/T that will support the full bandwidth capability of 1440 voice operated channels with 16 kb/s delta modulation. An input back-off of 3 dB is optimum for these small earth stations.

The maxima of the curves are quite flat. It is possible to vary the back-off around the optimum by ± 2 dB without losing more than 0.2 to 0.5 dB in carrier-to-noise ratio. Therefore, a near optimum operating point can be found from the simplified relationship in Table 3-5.

Table 3-5
Optimum Operating Point

EIRP + G/T (dB)	Input Back-off (dB)
51	2.5
53	3.5
55	4.5
57	6.0
59	8.0
61	9.0
63	10.0
65	11.0

The relationship in Table 3-5 is valid for C-band transmission of 36 MHz. For other conditions, the results can be scaled.

3.3.2 Channel Capacities

For the power limited condition, channel capacities are calculated as follows:

$$10 \log n = \text{EIRP}_s - \text{BO}_o - \text{PL}_D + \left(\frac{G}{T}\right)_E - y \\ - \left(\frac{C}{N_o}\right)_R - k + \text{SA} + \Delta M$$

where:

n = number of total voice channels

y = dB difference between down-link noise and total noise

$\left(\frac{C}{N_o}\right)_R$ = required carrier-to-noise density ratio at normal operation

= 53 dB Hz for 2-phase operation

SA = voice activity switching advantage, 4 dB

ΔM = additional margin for use at frequencies higher than 4 GHz.

For the bandwidth limited case, the channel capacity is given by

$$\eta = \frac{\text{Transponder Bandwidth in kHz}}{25}$$

The factor y depends on the selected operating point and on the satellite gain, as well as on the exact intermodulation contribution. For the power limited case, a transponder input back-off of 2.5 dB has been used and the corresponding y factor of 2 dB has been assumed. The small input back-off is due to voice switching, which brings a carrier-to-intermodulation noise advantage of 4 dB as shown in Figure 3-2.

The bandwidth limited capacities are as follows:

36 MHz Transponder	1440 Channels
50 MHz Transponder	2000 Channels
54 MHz Transponder	2160 Channels
125 MHz Transponder	5000 Channels
185 MHz Transponder	7400 Channels

For the power limited case, the following relationship was derived:

INTELSAT IV Global Beam

$$10 \log n = 1.9 + \left(\frac{G}{T} \right)_E$$

INTELSAT IV-A Regional Coverage

$$10 \log n = 8.9 + \left(\frac{G}{T} \right)_E$$

Domestic Satellite, C-Band

$$10 \log n = 12.9 + \left(\frac{G}{T} \right)_E$$

Domestic Satellite, K-Band

$$10 \log n = 5.4 + \left(\frac{G}{T} \right)_E$$

DSCS II, Global Beam

$$10 \log n = 0.9 + \left(\frac{G}{T} \right)_E$$

DSCS II, Spot Beam

$$10 \log n = 15.9 + \left(\frac{G}{T} \right)_E$$

To compensate for the higher rain attenuation and atmospheric absorption above 4 GHz, an additional margin, ΔM , of 1.5 dB was included for DSCS II and 3 dB for the domestic K-band transponder.

The results of the channel capacity calculations are shown in Figure 3-5.

3.4 TDM-PSK TRANSMISSION

In this system, the channels of each earth station are time division multiplexed and the composite bitstream is modulated onto a PSK carrier. Carrier sizes are 1, 2, 6, 20 and 200 channels for the low and high capacity traffic models and 14 through 33 channels for the medium capacity model. Each station requires a demodulator for each carrier it receives. Demand assignment is accomplished by switching of the demultiplexed receive channels.

Voice operated switching is not possible, except on the carriers with only one channel. The individual links are too small to permit the use of Speech Interpolation (DSI). Thus, the 4-dB voice activity advantage that was used in the SCPC system is not available with the TDM-PSK system.

The basic E_b/N_0 requirement per channel as well as the margin requirements are the same for TDM-PSK transmission and for SCPC transmission. Bandwidth requirements are also identical.

Therefore, the bandwidth limited capacities of this system and the SCPC system are identical, but the power limited capacities of this system are 4 dB lower than those of the SCPC system. The capacities for these systems are shown in Figure 3-6.

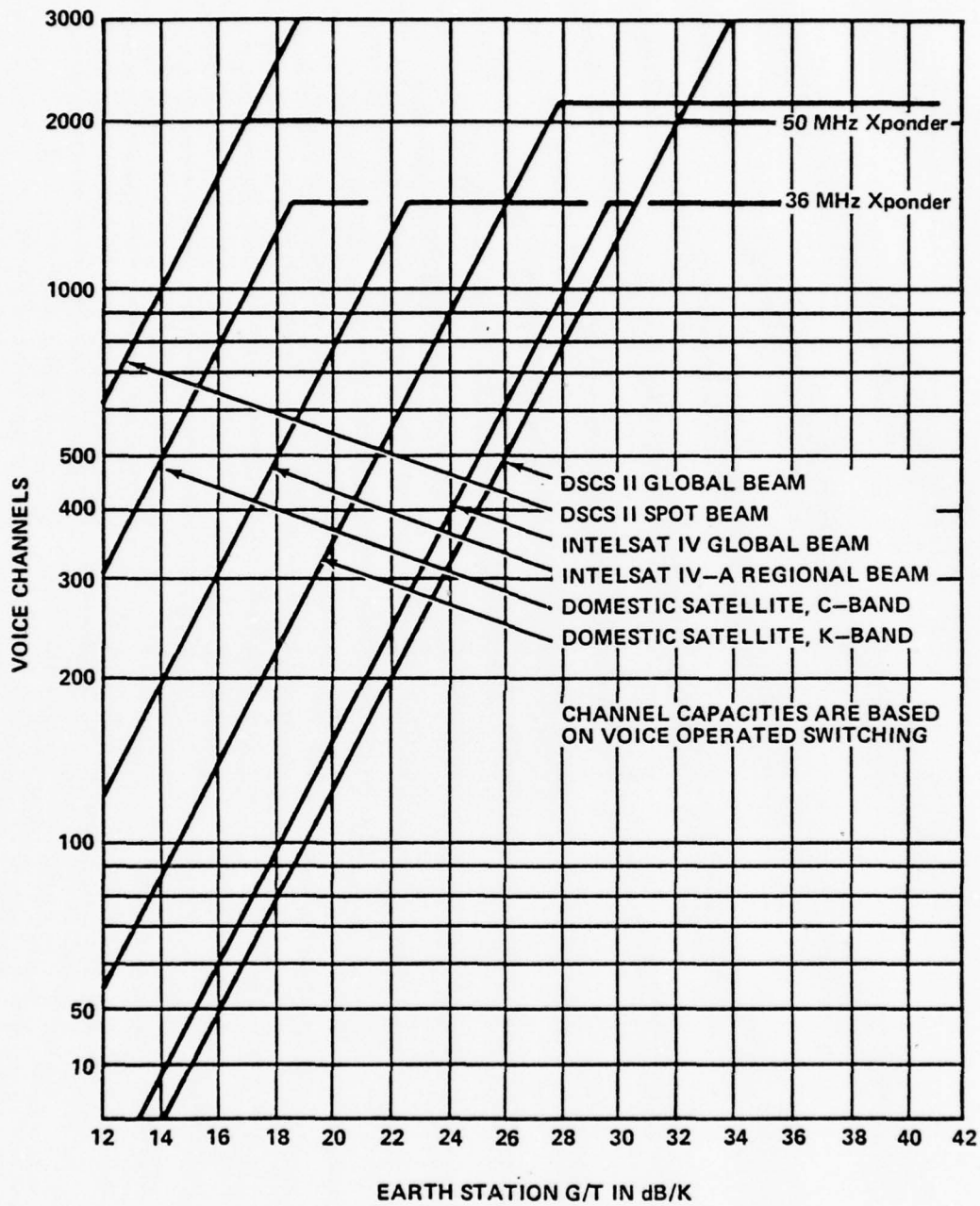


FIGURE 3-5
TRANSPONDER CAPACITY WITH SCPC TRANSMISSION

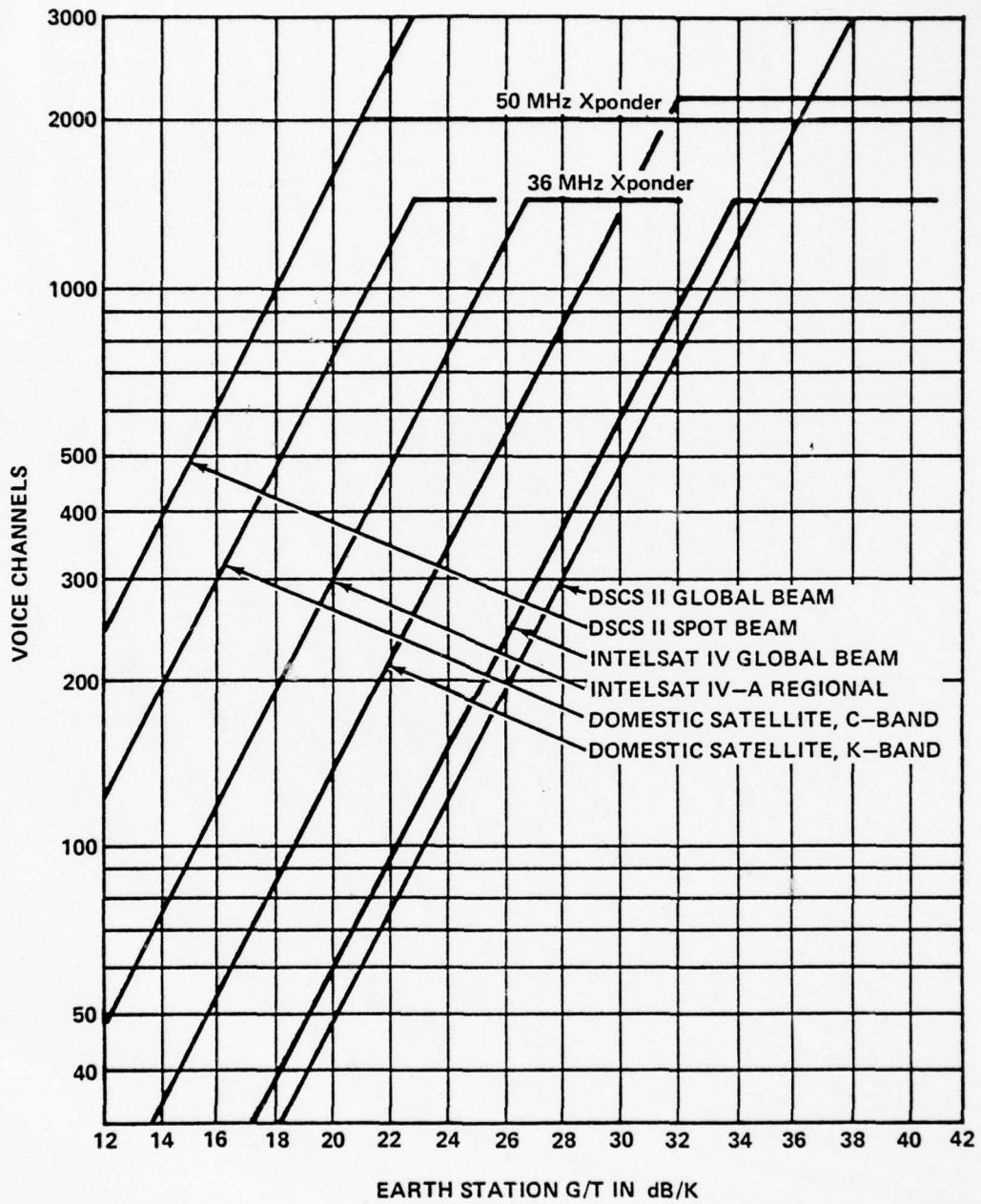


FIGURE 3-6

TRANSPONDER CAPACITY WITH TDM-PSK TRANSMISSION

3.5 TDM-PSK-TDMA SYSTEM

In this system, individual channels at an earth station are time division multiplexed and PSK modulated onto a carrier which is transmitted in a burst mode. The advantage of this system is that it eliminates multicarrier intermodulation losses. This would provide a basic power advantage of approximately 3 dB over the multi-carrier systems.

However, if the system works with earth stations which can support the total bandwidth of a transponder, additional losses relative to those with the other systems are incurred, due to intersymbol distortion at the high bit rates used as a result of the earth station HPA and satellite TWT nonlinearities. In a typical system, these losses are about 3 dB.

If the system operates with small earth stations, so that only about one-half of the available transponder bandwidth is occupied by the main lobe of the PSK spectrum, then the intersymbol distortion is reduced because the PSK side-lobes can be transmitted through the HPA and the satellite, thus reducing the envelope variations of the transmitted spectrum.

Voice operated switching is not possible and the individual links are too small to permit the use of Speech Interpolation. Thus, the 4 dB voice activity advantage that was used in the SCPC system is not available with the TDMA system.

A variation of this system is the transmission of individual channels per burst.

A major constraint of the TDMA system is that it requires the use of a full transponder. Sharing of the transponder with other services would require operation at back-off and would result in a carrier-to-noise ratio loss.

Under bandwidth limited conditions, the TDMA system capacity per transponder will be identical to that with the other two systems. In the power limited case, however, the TDMA capacity will be approximately that of the TDM-PSK system shown on Figure 3-6. Exact capacities have to be determined for each specific case.

Section 4
COST ASSUMPTIONS

Cost assumptions are required to permit the trade-off among earth station antenna size, earth station cost and transponder capacity. This trade-off will be performed to permit the synthesis of optimized configurations for each application.

4.1 SPACE SEGMENT COSTS

The trade-offs will be based on the assumption that a full transponder or a fraction of a transponder would be leased from any of the satellite systems under consideration. INTELSAT, as well as several domestic communications satellite carriers have developed rates for transponder lease. A few examples are given below.

INTELSAT has two rates for transponder lease. One applies for the lease of a protected transponder, i.e., in case of satellite failure a transponder will be made available in a spare satellite. The other rate applies for preemptable service, i.e., in case of satellite failure or during other contingencies, the service may be interrupted for prolonged periods.

The present rate for a pre-emptable transponder is \$1 Million per year. One-half or one-quarter of a transponder may be leased for \$500,000 or \$250,000, respectively. It is assumed, however, that the type of traffic considered in this study is too important to permit pre-emption. Therefore, only the rate for a protected transponder will be used.

The rate for a protected transponder is based on 360 units of space segment utilization. One unit corresponds to one CCIR quality telephony channel transmitted to an earth station with a G/T ratio of at least 40.7 dB/K. For 1976,

the rate for a unit of utilization was set at \$8,280. The corresponding rate for the lease of a transponder is approximately \$3 Million per year. No rate has yet been set for the lease of INTELSAT IV-A transponders. However, since the higher EIRP of these transponders permits the transmission of more channels, it may be assumed that the lease rate will be increased accordingly. A rate of \$4 Million per year is estimated.

Western Union has leased transponders to American Satellite Corporation for \$1.6 Million per year. It is expected that transponder lease costs in the future will be slightly higher, perhaps \$2 Million per year.

In determining a lease rate a communications satellite carrier has to consider the following factors: satellite and launch vehicle costs, satellite lifetime, administrative and other applicable costs, required revenues to cover costs and profits and competitive considerations. At times when a satellite is lightly loaded, a carrier may decide to lease transponders at a lower rate to attract additional traffic. At times when the satellite reaches saturation, the fully allocated costs will normally be used to determine charges.

Domestic K-band transponders are not yet available. A lease rate has been estimated which is higher than that of present C-band transponders, since more bandwidth and power is provided. The estimate for DSCS II transponders has been extrapolated from the commercial lease rates; it is not based on DSCS II program costs.

Table 4-1
Assumed Transponder Lease Rates

Transponder	Assumed Lease Price (in \$ Million Per Year)
INTELSAT IV, Global Beam	3
INTELSAT IV-A, Regional Beam	4
Domestic, C-Band	2
Domestic, K-Band	4
DSCS II, Global Beam	3
DSCS II, Spot Beam	4

4.2 GROUND SEGMENT COSTS

Unless otherwise noted, cost estimates in this section are for standard commercial equipment.

4.2.1 Antennas

Antenna cost estimates for 4/6 GHz antennas are based on quotations from various antenna suppliers during the year 1975. Actual quotations were averaged and costs were increased by 10% for inflation up to year end 1976 to obtain the data shown in Table 4-2.

Table 4-2
Antenna Cost Estimates
(\$1000)

Antenna Diameter (meters)	Antenna Costs for Quantities of:			Comments
	1	10	50	
3	17	16	14	Fiberglass antenna without motor control
4.5	21	18	16	Fiberglass antenna without motor control
8	62	54	48	Manual motor control
10	80	67	58	Manual motor control
11	96	80	70	Manual motor control
13	171	155	134	Step track
15	360	335	-	Step track
32	1400	-	-	Step track

4.2.2 Low Noise Amplifiers

These cost estimates are also averaged values from 1975 quotations, to which 10% was added to obtain year end 1976 estimates.

Table 4-3
Cost Estimates for Low Noise Amplifiers
(\$1000)

Noise Temperature (K)	Non-Redundant		Redundant	
	Quantity: 1 50		Quantity: 1 50	
50	29	24	60	51
55	28	23	58	48
65	24	21	50	44
80	19	17	41	35
90	18	16	39	34
130	15	13	32	28
500	4	3	10	7

4.2.3 High Power Amplifiers

Table 4-4
Cost Estimates for High Power Amplifiers

Saturated Power Rating	Non-Redundant	Redundant
	Quantity: 1 50	Quantity: 1 50
25 W TWT	21 16	47 36
100 W TWT	23 18	52 40
400 W TWT	35 26	76 58
600 W TWT	39 30	87 65
1200 W TWT	115 90	254 198
3000 W TWT	140 110	309 242
1500 W Klystron	47 41	106 90
3000 W Klystron	53 43	115 95

4.2.4 Frequency Converters

Table 4-5
Cost Estimates for Frequency Converters

Type	Quantity	
	1	50
Double conversion, frequency agile up or down converter	25	21
Single conversion, fixed frequency up or down converter	14	11

4.2.5 RF Equipment Costs at Higher Frequencies

To find RF component costs at 7/8 and 12/14 GHz, the 4/6 GHz component costs were used and multiplied by a factor of 1.3 to account for smaller commercial production quantities at the higher frequencies. Antennas were compared on the basis of equal diameter. Antenna gains were scaled in accordance with the frequencies.

4.2.6 SCPC Equipment Costs

(a) Commercial SCPC Equipment

- Central station with
redundant common
equipment: \$105 K + \$6 K per channel
- Remote station with
non-redundant common
equipment: \$ 12 K + \$6 K per channel

(b) Mil Spec SCPC Equipment

- Central station with
redundant common
equipment: \$215 K + \$12 K per channel
- Remote station with
non-redundant common
equipment: \$ 25 K + \$12 K per channel

The above figures are known DCC equipment costs. The prices for Mil Spec equipment were adjusted to remove the cost of Tempest associated hardware which is approximately \$3000 per channel. The costs do not include documentation, spare parts or non-recurring development.

The above figures show that equipment constructed to Mil Specs costs about twice as much as commercial equipment. The same factor of 2 will be applied to derive cost estimates for other earth station subsystems constructed to Mil Specs.

4.2.7 TDMA Equipment

The cost estimates are for commercial equipment. No redundancy is employed in the remote stations, but the central station is fully redundant except for channel equipment.

The system provides partial demand assignment. Each station transmits on all its channel units at all times, but the destination of each channel can be changed on demand. Channel assignment is controlled through a common signaling channel.

- Central station: \$340 K + \$2.4 K per channel
- Remote station: \$124 K + \$2.4 K per channel

4.2.8 PSK-FDMA Equipment

This system also provides partial demand assignment. Each station transmits one carrier with the allocated number of channels at all times. The destination of each channel can be changed on demand. A separate receive chain is required for each link. Redundancy is provided only at the central station.

- Central Station

Transmit Link	\$ 45 K + \$1.0 K per channel
Receive Link	\$ 29 K + \$1.7 K per channel
Common Equipment	\$ 55 K

- Remote Station

Transmit Link	\$ 20 K + \$1.0 K per channel
Receive Link	\$ 29 K + \$1.7 K per channel
Common Equipment	\$ 25 K

4.3 COST MODEL

The system optimization for each application will be based on minimum costs. Since space segment costs are expressed in annual lease costs, the earth station investment costs have to be converted to annual costs as well. System optimization will then be based on minimum annual systems costs.

Annual earth station costs will be estimated on the following basis:

(a) Depreciation

An average equipment life of 10 years will be assumed. The annual straight line depreciation therefore, will be 10% of initial equipment costs.

(b) Cost of Money

Cost of money is normally included in the calculation of the annual earth station costs. It is applied to the undepreciated portion of the earth station investment. Assuming a 10% cost of money, the average cost of money over the equipment life will be 5% without applying a present value factor.

(c) Replacement Parts

It will be assumed that the annual cost for replacement parts will be 3% of the initial equipment cost.

(d) Operating Costs

Operating costs are assumed to be proportional to complexity and therefore, cost of the equipment. It will be assumed that operating costs are 10% per year of initial equipment costs.

Based on the above considerations, annual earth station costs are assumed to be 28% of initial equipment costs.

Section 5
SYSTEMS OPTIMIZATION

In this section, the optimum systems configuration was determined for each combination of traffic model, satellite type and access technique. The study was limited to the use of a single transponder to satisfy traffic requirements.

5.1 SPACE SEGMENT COSTS VERSUS EARTH STATION G/T

The annual space segment cost was determined for each traffic model, satellite type and access technique as a function of earth station G/T. Where a model uses less than a full transponder, the cost allocation was made in proportion to the fraction of transponder power or bandwidth that was used. Bandwidth ratios were used in all bandwidth limited cases and power ratios were used in the power limited cases.

5.1.1 PSK-SCPC System

This system provides full demand assignment. Channels are transmitted only when required by traffic. In the power limited cases, the capacity was determined on the basis of satisfying the total Erlang load of the system with a probability of blocking of 0.01. Space segment channel requirements are summarized below:

Traffic Model	Low Capacity	Medium Capacity	High Capacity
Number of channel units	80	219	1100
Erlang load	19	133	492
Space segment channels	29	152	518

Transponder capacities versus G/T and annual space segment costs for the three traffic models are shown in Tables 5-1 through 5-6.

Table 5-1
Annual Space Segment Costs (\$1000)
SCPC-DSCS II Global Beam (50 MHz)
(\$3 M per Transponder)

G/T	Transponder Capacity	Space Segment Costs for		
		Low Cap. Model	Med. Cap. Model	High Cap. Model
12	19	--	--	--
14	31	2806	--	--
16	49	1771	--	--
18	78	1117	--	--
20	123	705	--	--
22	195	445	2339	--
24	309	281	1476	--
26	490	177	931	--
28	776	112	587	2002
30	1230	70	371	1263
32	1950	45	234	797
34	2000	44	229	777

Note: Transponder capacities are based on formulas given in section 3; space segment costs are based on transponder lease rates shown in Table 4-1.

Table 5-2
Annual Space Segment Costs (\$1000)
SCPC-DSCS II Spot Beam (50 MHz)
(\$4 M per Transponder)

G/T	Transponder Capacity	Space Segment Costs for		
		Low Cap. Model	Med. Cap. Model	High Cap. Model
12	617	188	986	3360
14	977	119	622	2120
16	1549	75	393	1338
18	2000	58	304	1036

Note: Transponder capacities are based on formulas given in section 3; space segment costs are based on transponder lease rates shown in Table 4-1.

Table 5-3
Annual Space Segment Costs (\$1000)
SCPC-Domestic Satellite, C-Band
(\$2 M per Transponder)

G/T	Transponder Capacity	Space Segment Costs for		
		Low Cap. Model	Med. Cap. Model	High Cap. Model
12	309	188	984	--
14	490	118	621	--
16	776	75	392	1335
18	1230	47	247	842
20	1440	40	211	719

Note: Transponder capacities are based on formulas given in section 3; space segment costs are based on transponder lease rates shown in Table 4-1.

Table 5-4
Annual Space Segment Costs (\$1000)
SCPC-Domestic Satellite, K-Band
(\$4 M per Transponder)

G/T	Transponder Capacity	Space Segment Costs for		
		Low Cap. Model	Med. Cap. Model	High Cap. Model
12	55	2111	--	--
14	87	1332	--	--
16	138	840	--	--
18	219	530	2779	--
20	347	335	1753	--
22	550	211	1106	3770
24	871	133	698	2379
26	1380	84	440	1501
28	2160	54	281	959

Note: Transponder capacities are based on formulas given in section 3; space segment costs are based on transponder lease rates shown in Table 4-1.

Table 5-5
Annual Space Segment Costs (\$1000)
SCPC-INTELSAT IV Global Beam
(\$3 M per Transponder)

G/T	Transponder Capacity	Space Segment Costs for		
		Low Cap. Model	Med. Cap. Model	High Cap. Model
12	25	--	--	--
14	39	2236	--	--
16	62	1411	--	--
18	93	890	--	--
20	155	562	2944	--
22	245	354	1858	--
24	389	224	1172	--
26	617	141	740	2520
28	977	89	467	1590
30	1445	60	317	1079

Note: Transponder capacities are based on formulas given in section 3; space segment costs are based on transponder lease rates shown in Table 4-1.

Table 5-6
Annual Space Segment Costs (\$1000)
SCPC-INTELSAT IV-A Regional Coverage
(\$4 M per Transponder)

G/T	Transponder Capacity	Space Segment Costs for		
		Low Cap. Model	Med. Cap. Model	High Cap. Model
12	123	943	--	--
14	195	595	3118	--
16	309	375	1967	--
18	490	237	1241	--
20	776	149	783	2669
22	1230	94	494	1684
24	1440	81	422	1439

Note: Transponder capacities are based on formulas given in section 3; space segment costs are based on transponder lease rates shown in Table 4-1.

5.1.2 TDM-PSK-FDMA System

This system provides only partial demand assignment. It provides a variable destination capability for all channels, but all channels from all earth stations are always transmitted, regardless of instantaneous traffic requirement. Thus, the required space segment capacity equals the total number of channel units in the system. Transponder channel capacities and space segment costs for the three traffic models as a function of earth station G/T are shown in Tables 5-7 through 5-12.

Table 5-7
Annual Space Segment Costs (\$1000)
TDM-PSK - DSCS II Global Beam (50 MHz)
(\$3 M per Transponder)

G/T	Transponder Capacity	Space Segment Costs for		
		Low Cap. Model	Med. Cap. Model	High Cap. Model
12	8	--	--	--
14	12	--	--	--
16	19	--	--	--
18	31	--	--	--
20	49	--	--	--
22	78	--	--	--
24	123	1945	--	--
26	195	1227	--	--
28	309	774	2127	--
30	490	489	1342	--
32	776	308	847	--
34	1230	194	534	2682
36	1950	123	337	1692
38	2000	121	330	1650

Note: Transponder capacities are based on formulas given in section 3; space segment costs are based on transponder lease rates shown in Table 4-1.

Table 5-8
Annual Space Segment Costs (\$1000)
TDM-PSK - DSCS II Spot Beam (50 MHz)
(\$4 M per Transponder)

G/T	Transponder Capacity	Space Segment Costs for		
		Low Cap. Model	Med. Cap. Model	High Cap. Model
12	245	1305	3569	--
14	389	822	2252	--
16	617	519	1421	--
18	977	328	896	--
20	1549	207	566	2841
22	2000	160	438	2200

Note: Transponder capacities are based on formulas given in section 3; space segment costs are based on transponder lease rates shown in Table 4-1.

Table 5-9
Annual Space Segment Costs (\$1000)
TDM-PSK - Domestic Satellite, C-Band
(\$2 M per Transponder)

G/T	Transponder Capacity	Space Segment Costs for		
		Low Cap. Model	Med. Cap. Model	High Cap. Model
12	123	1299	--	--
14	195	819	--	--
16	309	519	1418	--
18	490	326	895	--
20	776	207	565	--
22	1230	130	356	1788
24	1440	110	304	1527

Note: Transponder capacities are based on formulas given in section 3; space segment costs are based on transponder lease rates shown in Table 4-1.

Table 5-10
Annual Space Segment Costs (\$1000)
TDM-PSK - Domestic Satellite, K-Band
(\$4 M per Transponder)

G/T	Transponder Capacity	Space Segment Costs for		
		Low Cap. Model	Med. Cap. Model	High Cap. Model
12	22	--	--	--
14	35	--	--	--
16	55	--	--	--
18	87	3674	--	--
20	138	2317	--	--
22	219	1462	4000	--
24	347	924	2526	--
26	550	582	1594	--
28	871	367	1006	--
30	1380	232	634	3187
32	2160	149	405	2036

Note: Transponder capacities are based on formulas given in section 3; space segment costs are based on transponder lease rates shown in Table 4-1.

Table 5-11
Annual Space Segment Costs (\$1000)
TDM-PSK - INTELSAT IV Global Beam
(\$3 M per Transponder)

G/T	Transponder Capacity	Space Segment Costs for		
		Low Cap. Model	Med. Cap. Model	High Cap. Model
12	10	--	--	--
14	15	--	--	--
16	25	--	--	--
18	39	--	--	--
20	62	--	--	--
22	98	2455	--	--
24	155	1550	--	--
26	245	977	2677	--
28	389	618	1689	--
30	617	389	1066	--
32	977	246	673	--
34	1440	166	457	2291

Note: Transponder capacities are based on formulas given in section 3; space segment costs are based on transponder lease rates shown in Table 4-1.

Table 5-12
Annual Space Segment Costs (\$1000)
TDM-PSK - INTELSAT IV-A Regional Coverage
(\$4 M per Transponder)

G/T	Transponder Capacity	Space Segment Costs for		
		Low Cap. Model	Med. Cap. Model	High Cap. Model
12	49	--	--	--
14	78	--	--	--
16	123	2601	--	--
18	195	1641	--	--
20	309	1034	2834	--
22	490	654	1788	--
24	776	411	1128	--
26	1230	259	712	3576
28	1440	223	608	3056

Note: Transponder capacities are based on formulas given in section 3; space segment costs are based on transponder lease rates shown in Table 4-1.

5.1.3 TDM-PSK-TDMA System

With this system, it is normally assumed that the total power of a transponder is available to the TDMA system. In this case, the space segment cost is equal to the transponder lease rates as shown in Table 4-1.

However, it is also possible to share the transponder between the TDMA system and other services, although this requires careful study of the resulting interference between the systems. This case is only included for completeness; it is not considered promising, since channel capacities are lower and earth station equipment costs are higher than in the SCPC case.

Channel capacity per transponder is calculated as follows:

$$10 \log n = \text{EIRP}_S - \text{BO}_O - \text{PL}_D + \left(\frac{G}{T}\right)_E - y - M_I - \left(\frac{C}{N_O}\right)_R - k - \Delta M$$

where:

- y = degradation of down-link C/N due to up-link and intermodulation noise; an average value of 3 dB* is expected for this mode of operation
- M_I = equivalent degradation of C/N due to inter-symbol distortion; an average value of 3 dB** is expected for this mode of operation.

* This value is higher than that used for SCPC, since TDMA requires a larger backoff to reduce intersymbol distortion and adjacent transponder interference due to spectrum spreading. An input backoff of at least 4 dB is required for TDMA.

** SCPC does not suffer from this degradation due to the low bit rate and small bandwidth used for each carrier.

ΔM = additional margin at frequencies above 4 GHz;
1.5 dB was used for DSCS II and 3 dB for K-band
operation.

Other quantities are as defined in section 3.3.

For the bandwidth limited case, the capacity is
given by

$$n = \frac{\text{Transponder bandwidth in kHz}}{25}$$

For the power limited case, the following relation-
ship was derived, based on the above formula:

DSCS II, Global Beam

$$10 \log n = -8.6 + \left(\frac{G}{T}\right)_E$$

DSCS II, Spot Beam

$$10 \log n = 6.4 + \left(\frac{G}{T}\right)_E$$

Domestic Satellite, C-Band

$$10 \log n = 3.4 + \left(\frac{G}{T}\right)_E$$

Domestic Satellite, K-Band

$$10 \log n = -4.1 + \left(\frac{G}{T}\right)_E$$

INTELSAT IV, Global Beam

$$10 \log n = -7.6 + \left(\frac{G}{T}\right)_E$$

INTELSAT IV-A, Regional Beam

$$10 \log n = -0.6 + \left(\frac{G}{T}\right)_E$$

Channel capacities and space segment costs for this mode of operation are shown in Tables 5-13 through 5-18.

Table 5-13
Annual Space Segment Costs (\$1000)
TDM-PSK-TDMA-FDMA
DSCS II, Global Beam (50 MHz)
(\$3 M per Transponder)

G/T	Transponder Capacity	Space Segment Costs for		
		Low Cap. Model	Med. Cap. Model	High Cap. Model
26	55	--	--	--
28	87	2756	--	--
30	138	1739	--	--
32	219	1097	--	--
34	347	692	1895	--
36	550	437	1196	--
38	871	276	754	--
40	1380	174	476	

Note: Channel capacities are calculated with formulas shown in section 5.1.3; space segment costs are based on transponder lease rates given in Table 4-1.

Table 5-14
Annual Space Segment Costs (\$1000)
TDM-PSK-TDMA-FDMA
DSCS II Spot Beam (50 MHz)
(\$4 M per Transponder)

G/T	Transponder Capacity	Space Segment Costs for		
		Low Cap. Model	Med. Cap. Model	High Cap. Model
12	69	--	--	--
14	110	2918	--	--
16	174	1841	--	--
18	275	1162	3181	--
20	437	733	2007	--
22	692	463	1266	--
24	1096	292	799	--
26	1738	184	504	2532
28	2000	160	438	2200

Note: Channel capacities are calculated with formulas shown in section 5.1.3; space segment costs are based on transponder lease rates given in Table 4-1.

Table 5-15
Annual Space Segment Costs (\$1000)
TDM-PSK-TDMA-FDMA
Domestic Satellite, C-Band
(\$2 M per Transponder)

G/T	Transponder Capacity	Space Segment Costs for		
		Low Cap. Model	Med. Cap. Model	High Cap. Model
18	138	1159	--	--
20	219	731	--	--
22	347	461	1262	--
24	550	291	796	--
26	871	184	503	--
28	1380	116	317	--
30	1440	111	304	--

Note: Channel capacities are calculated with formulas shown in section 5.1.3; space segment costs are based on transponder lease rates given in Table 4-1.

Table 5-16
Annual Space Segment Costs (\$1000)
TDM-PSK-TDMA-FDMA
Domestic Satellite, K-Band
(\$4 M per Transponder)

G/T	Transponder Capacity	Space Segment Costs for		
		Low Cap. Model	Med. Cap. Model	High Cap. Model
26	155	2066	--	--
28	245	1304	--	--
30	389	823	2252	--
32	617	519	1421	--
34	977	327	897	--
36	1549	207	566	2841
38	2160	148	406	2037

Note: Channel capacities are calculated with formulas shown in section 5.1.3; space segment costs are based on transponder lease rates given in Table 4-1.

Table 5-17
Annual Space Segment Costs (\$1000)
TDM-PSK-TDMA-FDMA
INTELSAT IV - Global Beam
(\$3 M per Transponder)

G/T	Transponder Capacity	Space Segment Costs for		
		Low Cap. Model	Med. Cap. Model	High Cap. Model
28	110	2182	--	--
30	174	1377	--	--
32	275	869	2389	--
34	437	548	1507	--
36	692	346	951	--
38	1096	218	600	--
40	1440	167	456	--

Note: Channel capacities are calculated with formulas shown in section 5.1.3; space segment costs are based on transponder lease rates given in Table 4-1.

Table 5-18
Annual Space Segment Costs (\$1000)
TDM-PSK-TDMA-FDMA
INTELSAT IV-A - Regional Coverage
(\$4 M per Transponder)

G/T	Transponder Capacity	Space Segment Costs for		
		Low Cap. Model	Med. Cap. Model	High Cap. Model
22	138	2318	--	--
24	219	1463	--	--
26	347	923	2524	--
28	550	582	1593	--
30	871	367	1005	--
32	1380	232	634	--
34	1440	146	608	--

Note: Channel capacities are calculated with formulas shown in section 5.1.3; space segment costs are based on transponder lease rates given in Table 4-1.

5.2 LNR, HPA AND ANTENNA COMBINATIONS

In configuring an earth station, different combinations of antenna diameter and LNR noise temperature can be considered to obtain the lowest cost combination for a given G/T. Different combinations of antenna diameter and HPA power will produce a given earth station EIRP. The antenna diameter may also determine whether or not tracking is required. The EIRP requirement for the earth station depends on the satellite transponder gain, on the number of channels transmitted and on the G/T of the receive earth station. All these factors have been considered in steps so as to obtain an understanding of the essential relationships.

5.2.1 Minimum Cost G/T Combinations

The receive figure of merit for earth terminals, the gain-to-noise temperature ratio, is calculated from antenna gain, antenna noise temperature, transmission line losses and receiver noise temperature. The receive antenna gain was based on an efficiency of 60%. The antenna noise temperature is assumed to be 30 K and the transmission line losses are assumed to introduce a loss of 20 K. G/T as a function of antenna diameter and receiver noise temperature is shown in Table 5-19. Quantities of 50 units are assumed. All equipment is non-redundant. The trade-off is performed for a receive frequency of 4 GHz, using commercial equipment.

Antenna gain is calculated as follows:

$$G = 10 \log \eta \frac{D^2 \pi^2}{\lambda^2}$$

where:

G = antenna gain in dB

η = efficiency, assumed to be 60%

D = antenna diameter in m

λ = wavelength in m; at 4 GHz, $\lambda = 0.075$ m

This formula can be written as:

$$G = 30.2 + 20 \log D$$

The information of Table 5-19 has been plotted in Figure 5-1 to find the lowest cost combinations of antennas and receivers for a given G/T, for the discrete values of noise temperature and antenna gains shown in Section 4.

Figures 5-2 and 5-3 show a continuous plot of antenna cost versus antenna gain and receiver cost versus total systems noise temperature. From this information, the curves in Figure 5-4 have been plotted from which the following lowest cost combination of antenna gain and receiver noise temperature have been developed:

Table 5-19
G/T Versus Antenna Diameter and Receiver Noise Temperature
(at 4 GHz)

Antenna Diameter (m)		3	4.5	8	10	11	13	15	32
Receiver** Temperature (K)	Gain (dB)	39.7	43.3	48.3	50.2	51.0	52.5	53.7	60.3
	Cost (\$1000)	14	16	48	58	70	134	360*	1400*
Receiver** Temperature (K)	Cost (\$1000)								
		24	23.3	28.3	30.2	31	32.5	33.7	40.3
50		19.7	23.3	28.3	30.2	31	32.5	33.7	40.3
55		19.5	23.1	28.1	30.0	30.8	32.3	33.5	40.1
65		19.1	22.7	27.7	29.6	30.4	31.9	33.1	39.7
80		18.6	22.2	27.2	29.1	29.9	31.4	32.6	39.2
90		18.2	21.8	26.8	28.7	29.5	31.0	32.2	38.8
130		17.1	20.7	25.7	27.6	28.4	29.9	31.1	37.7
500		12.3	15.9	20.9	22.8	23.6	25.1	26.3	32.9

* Quantity of 1

**Receiving system noise temperature is 50 K higher

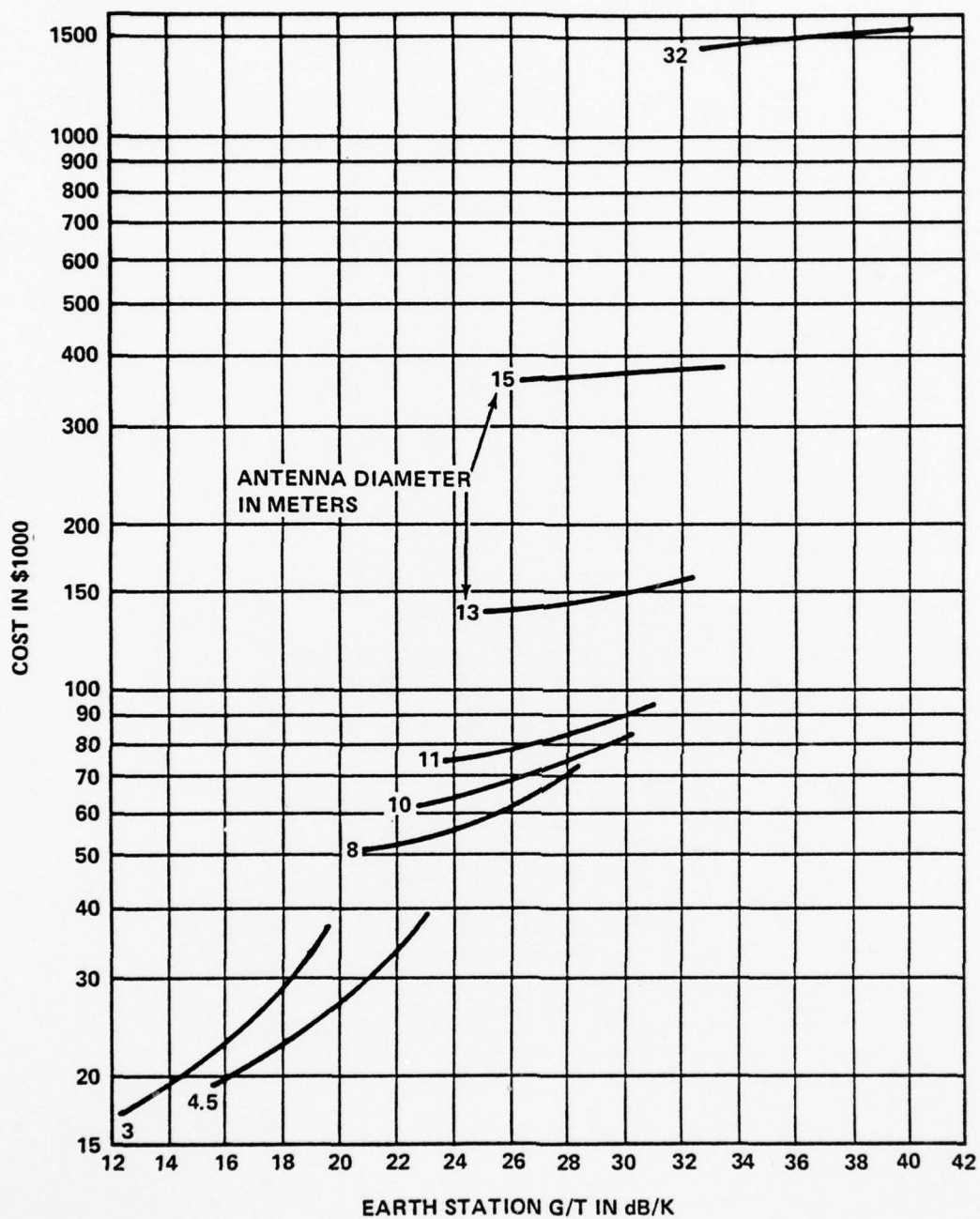


FIGURE 5-1
COST VERSUS EARTH STATION G/T

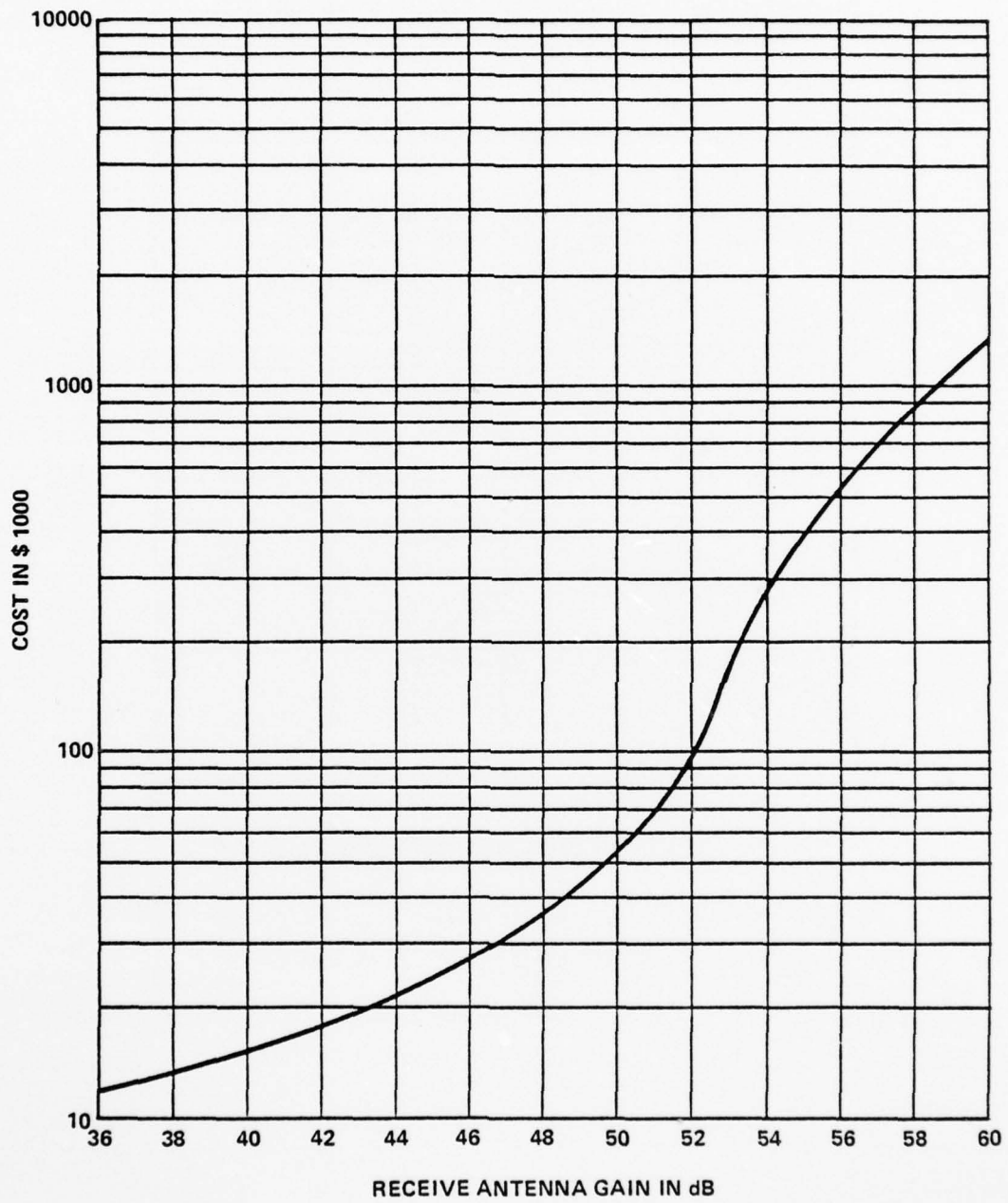


FIGURE 5-2
ANTENNA COST VERSUS ANTENNA GAIN

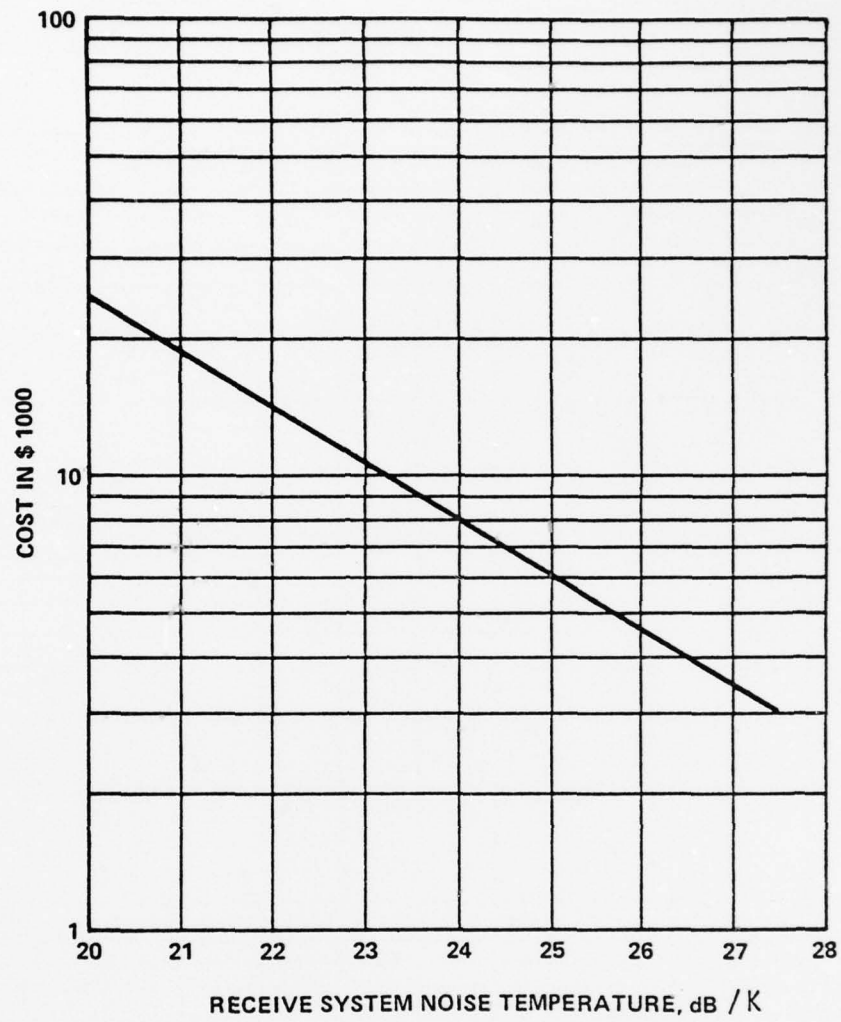


FIGURE 5-3
LOW NOISE RECEIVER COST
VERSUS SYSTEM NOISE TEMPERATURE

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COMMUNICATIONS SYSTEMS MODELING STUDY.(U)
NOV 76 R STAMMIGER, W L PRITCHARD

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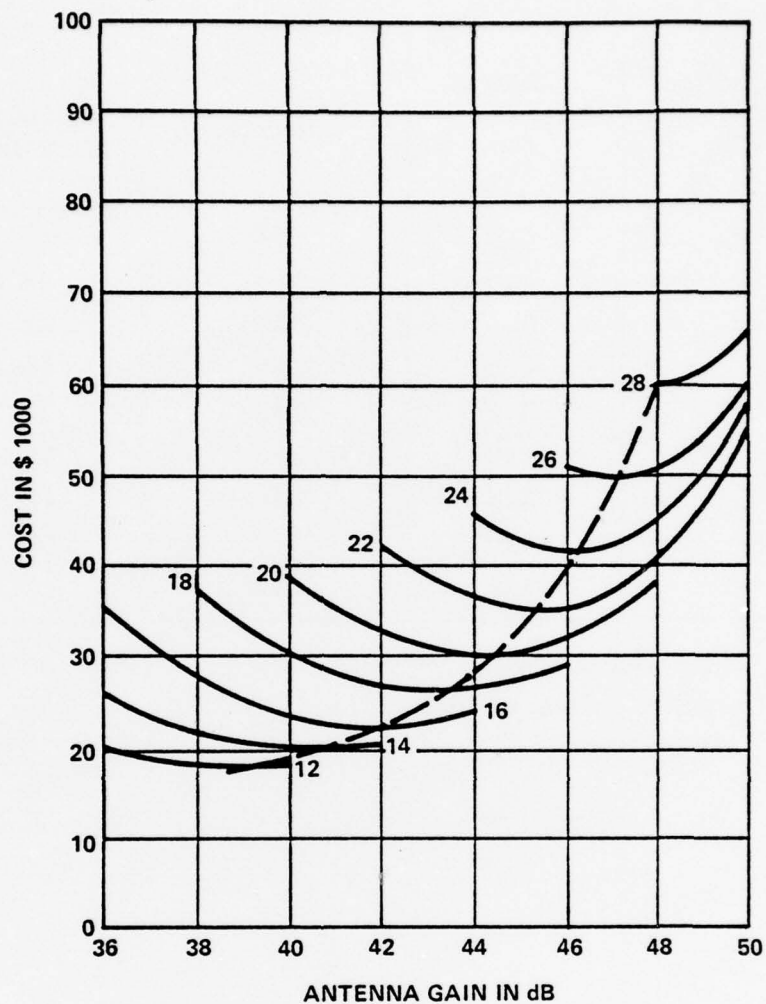


FIGURE 5-4
MINIMUM COST FOR DIFFERENT VALUES OF G/T

G/T	Antenna Gain (dB)	Antenna Diameter (m)	Receiver* Noise Temperature (K)	Cost of Antenna/ Receiver Combination (\$1000)
12	39	2.8	450	17.5
14	41	3.5	450	20.0
16	42	3.9	350	22.0
18	43.5	4.6	300	26.0
20	44.5	5.2	230	30.0
22	45.5	5.8	170	35.0
24	46	6.2	108	42.0
26	47	6.9	75	50.0
28	48	7.8	50	60.0

Higher G/T ratios are always obtained by using the receiver with the lowest noise temperature.

* The receiving system noise temperature is higher by 50 K, as described in section 5.2.1.

5.2.2 Minimum Cost EIRP at 6 GHz

Single carrier saturated EIRP will be determined for different antenna/HPA combinations in order to find the combinations with the lowest cost for a given EIRP. A loss of 2 dB will be assumed between HPA output and antenna.

Costs of HPAs are plotted in Figure 5-5. Minimum cost for a given EIRP is plotted in Figure 5-6. Cost is plotted versus transmit antenna gain minus line losses. For EIRPs above 80 dBW the minimum cost solution would require an HPA with more than 3 kW. For lower values of EIRP, the optimum combinations are shown below:

EIRP (dBW)	Antenna Gain (dB)	Antenna Diameter (m)	HPA Power (Watts)	Cost (\$1000)
48	38	2.1	10	25
52	39	2.3	20	27.5
56	40	2.6	40	30
60	41	2.9	80	34
64	42	3.3	160	39
68	43	3.7	320	44
72	44	4.1	640	50
76	45	4.6	1300	57
80	47	5.8	2000	65

Since the minimum cost is achieved with relatively large power levels and small antenna diameters, the selection of the antenna diameter will generally be determined by the G/T requirement.

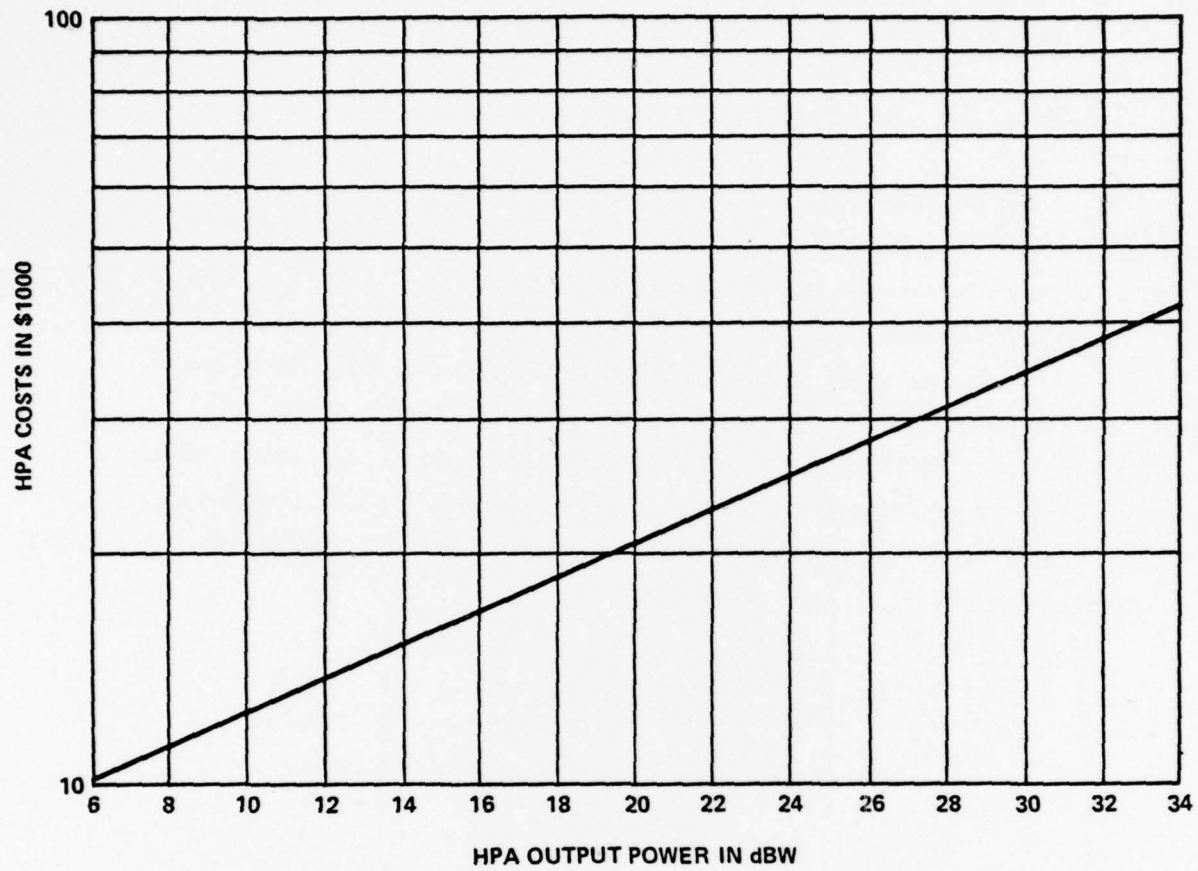


FIGURE 5-5
HPA COST VERSUS OUTPUT POWER
AT 6 GHz

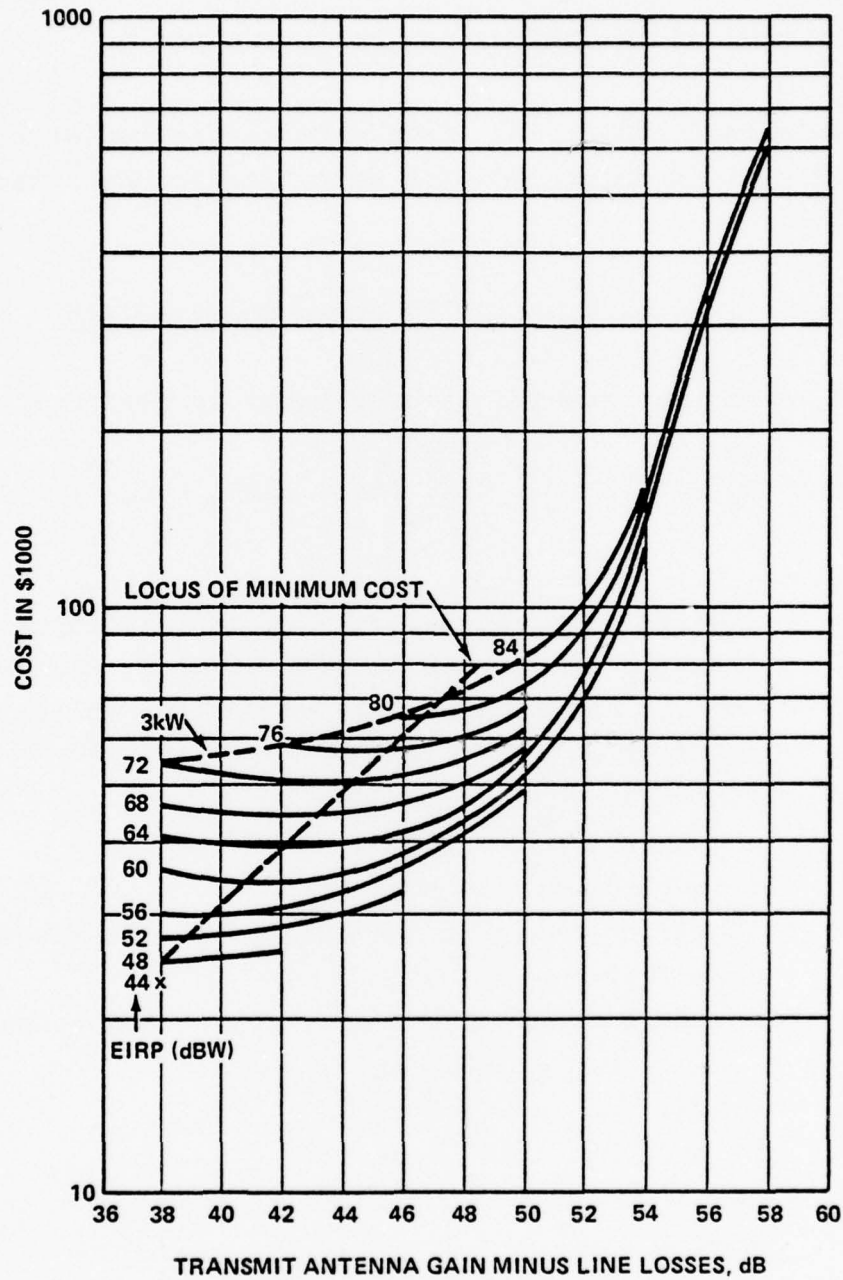


FIGURE 5-6
MINIMUM COST FOR EIRP
AT 6 GHz

5.3 SYSTEMS OPTIMIZATION FOR SCPC TRANSMISSION

In this section, the optimum configuration of an SCPC system will be determined for each traffic model and each satellite type.

5.3.1 Earth Station EIRP and RF Power Requirements

RF power per channel is calculated as follows:

$$P_C = W_S - G_m^2 - BO_I - 10 \log n + PL_u - G_T$$

where:

- P_C = average RF power per channel at HPA output, dBW
- W_S = transponder saturation flux density, dBW/m²
- G_m^2 = gain of one square meter at up-link frequency;
 - at 6 GHz, $G_m^2 = 37.0$ dB,
 - at 8 GHz, $G_m^2 = 39.5$ dB,
 - at 14 GHz, $G_m^2 = 44.4$ dB
- BO_I = transponder input back-off
- n = number of channels per transponder (transponder capacity)
- PL_u = pathloss at up-link frequency; at 30° elevation,
 - 6 GHz, $PL_u = 199.7$ dB,
 - 8 GHz, $PL_u = 202.2$ dB,
 - 14 GHz, $PL_u = 207.1$ dB
- G_t = net transmit antenna gain (antenna gain minus line losses).

The power per channel as calculated with this formula is shown in Table 5-20.

Table 5-20
Earth Station HPA Power per Channel
for SCPC Transmission

Satellite	W_s (dBW/m ²)	G/T (dB/K)	n	BO _I (dB)	G (dB)	P _C (Watts)
Domsat C-Band EIRP = 33 dBW	-83	12	309	3	40.4	13.5
		14	490	3	42.5	5.4
		16	776	3	43.5	2.7
		18	1230	3	45	1.2
		20	1440	3	46	0.8
		22	1440	4	47	0.5
		24	1440	6	47.5	0.3
		26	1440	8	58.5	0.15
		28	1440	9	49.5	0.09
		30	1440	10	51.5	0.05
INTELSAT IV Global Beam EIRP = 22 dBW	-73	14	39	3	42.5	675
		16	62	3	43.5	337
		18	98	3	45	150
		20	155	3	46	76
		22	245	3	47	38
		24	389	3	47.5	21
		26	617	3	48.5	11
		28	977	3	49.5	5.4
		30	1440	3	51.5	2.3
		32	1440	4	53.5	1.2

(Continued)

Table 5-20
Earth Station HPA Power per Channel
for SCPC Transmission (continued)

Satellite	W_s (dBW/m ²)	G/T (dB/K)	n	BOI (dB)	G (dB)	P_c (Watts)
INTELSAT IV-A Regional Coverage EIRP = 29 dBW	-75	12	123	3	40.5	214
		14	195	3	42.5	85
		16	309	3	43.5	43
		18	490	3	45	19
		20	776	3	46	10
		22	1230	3	47	4.8
		24	1440	3.5	47.5	3.2
		26	1440	4.5	48.5	2.0
		28	1440	6	49.5	1.2
		30	1440	8	51.5	0.5
		32	1440	9	53.5	0.2
Domsat K-Band EIRP = 38 dBW	-83	12	55	3	37	170
		14	87	3	39	68
		16	138	3	41	27
		18	219	3	43	11
		20	347	3	45	4.3
		22	550	3	47	1.7
		24	871	3	49	0.7
		26	1380	3.5	51	0.24
		28	2160	4.5	53	0.08
		30	2160	6	55	0.03
		32	2160	8	57	0.014
		34	2160	9	59	0.007

(continued)

Table 5-20
Earth Station HPA Power per Channel
for SCPC Transmission (continued)

Satellite	W_s (dBW/m ²)	G/T (dB/K)	n	BOI (dB)	G (dB)	P _C (Watts)
DSCS II Global Beam EIRP = 28 dBW 115 dB gain	-78	14	49	3	39	600
		16	49	3	41	240
		18	78	3	43	95
		20	123	3	45	38
		22	195	3	47	15
		24	309	3	48	7.6
		26	490	3	50	3.0
		28	776	3	52	1.2
		30	1230	3.5	54	0.4
		32	1950	4.5	56	0.13
		34	2000	6	57	0.07
		36	2000	8	59	0.03
		12	617	3	37	12.1
DSCS II Spot Beam EIRP = 43 dBW 105 dB gain		14	977	3.5	39	4.3
		16	1549	4.5	41	1.4
		18	2000	6	43	0.5
		20	2000	8	45	0.19
		22	2000	9	47	0.09
		24	2000	10	48	0.059
		26	2000	11	50	0.030
		28	2000	12	52	0.015
		30	2000	12	54	0.009
		32	2000	12	56	0.006
		12	617	3	37	12.1
		14	977	3.5	39	4.3
		16	1549	4.5	41	1.4

For the calculation of earth station transmit power requirements for different G/T ratios at K-band, it was necessary to define the relationship between G/T and transmit antenna gain. This was based on the SBS filing with the FCC where 5-meter antennas are used with a receiving system noise temperature at 12 GHz of 225 K. This system noise temperature was used for all G/T ratios in the study. It is expected, however, that detailed optimization at these frequencies will also result in higher noise temperature at very low G/T ratios and lower noise temperatures at higher G/T ratios.

For operation with DSCS II, system noise temperatures shown in Table 5-21 were calculated. Earth station characteristics are taken from Table 2-9.

Table 5-21
DSCS II Earth Station Characteristics

Antenna Diameter (feet)	Antenna Diameter (meters)	G/T (dB/K)	G (dB)	T (dB)	T (K)
4	1.2	12	37.3	25.3	340
8	2.4	18	43.3	25.3	340
18	5.5	26.5	50.5	24.0	250
40	12.2	34	57.4	23.4	220
60	18.3	39	60.9	21.9	155

$$G = 10 \log \eta \frac{D^2 \pi^2}{\lambda^2} = 35.7 + 20 \log D$$

$$\eta = 60\%$$

$$\lambda = 4 \text{ cm}$$

The transmit power levels calculated in this section are based on the total channel capacity of the transponders which assumes an average voice switching advantage of 4 dB. Accordingly, to find the transmit power level for an individual channel, 4 dB must be added to the power shown in Table 5-20. For an earth station that transmits more than one channel, a voice switching advantage may be used that varies from 0 to 4 dB, depending on the number of channels transmitted. In addition, the HPA must be operating at a back-off that depends on the system operating conditions.

5.3.2 Incremental Systems Costs Versus G/T

The optimum systems configuration was determined for different traffic models and satellite types. A detailed example of this determination is shown in Table 5-22 for the case of the low capacity traffic model and the Domestic C-band transponder. The results of the optimization are shown in Figure 5-7.

In the cost comparison, only those cost elements have been entered that change with the change of G/T. This includes antenna costs, HPA costs and LNR costs. These subsystem costs have been multiplied by a factor of 1.5 to obtain installed costs with spares. Annual costs were found by multiplying the total by the annualizing factor of 0.28.

Because of the low traffic requirements and the efficient space segment utilization of the PSK-SCPC system, the space segment costs are low and the ground segment costs dominate in this model. Minimum costs are achieved with a G/T of 18. This corresponds to an antenna diameter of approximately 4.5 meters. Because of FCC sidelobe requirements, a slightly larger antenna would probably be chosen in practice.

Table 5-22
Annual Systems Costs for Low Capacity Model,
SCPC Transmission and Domsat C-Band Transponder

G/T	Antenna Gain (dbi)	Antenna Cost (\$1000)	RX Noise Temp. (K)	RX Cost (\$1000)	RX & Antenna Cost for 26 Systems (\$1000)	HPA Cost 1 Ch. (\$1000)	HPA Cost 2 Ch. (\$1000)	HPA Cost 6 Ch. (\$1000)	HPA Cost 20 Ch. (\$1000)	Total Ground Segment Investment Costs (\$1000)	Annual Segment Ground Costs (\$1000)	Annual Segment Space Costs (\$1000)	Total Annual Costs (\$1000)
12	39	14	450	3.5	455	17	21	33	80	1080	453	188	641
14	41	17	450	3.5	533	13	18	26	65	1038	435	118	553
16	42	18	350	4.5	585	11	16	21	55	1015	426	75	501
18	43.5	21	300	5.5	689	10	13	18	45	1054	443	47	490
20	44.5	23	230	6.5	767	10	12	17	45	1117	469	40	509
22	45.5	25	170	9.0	884	10	11	15	45	1214	510	40	550
26	46	27	108	14.0	1066	10	10	13	45	1376	578	40	618
26	47	31	75	18.0	1274	10	10	12	45	1600	672	40	712
28	48	36	50	24	1560	10	10	11	45	1870	785	40	825
30	50	52	50	24	1976	10	10	10	45	2286	960	40	1000
32	52	100	50	24	3224	10	10	10	45	3534	1484	40	1524
34	54	280	50	24	7904	10	10	10	45	8414	3450	40	3490
36	56	530	50	24	14400	10	10	10	45	14700	6174	40	6214
38	58	860	50	24	23000	10	10	10	45	23310	9790	40	9830
40	60	1400	50	24	37000	10	10	10	45	37310	15670	40	15710

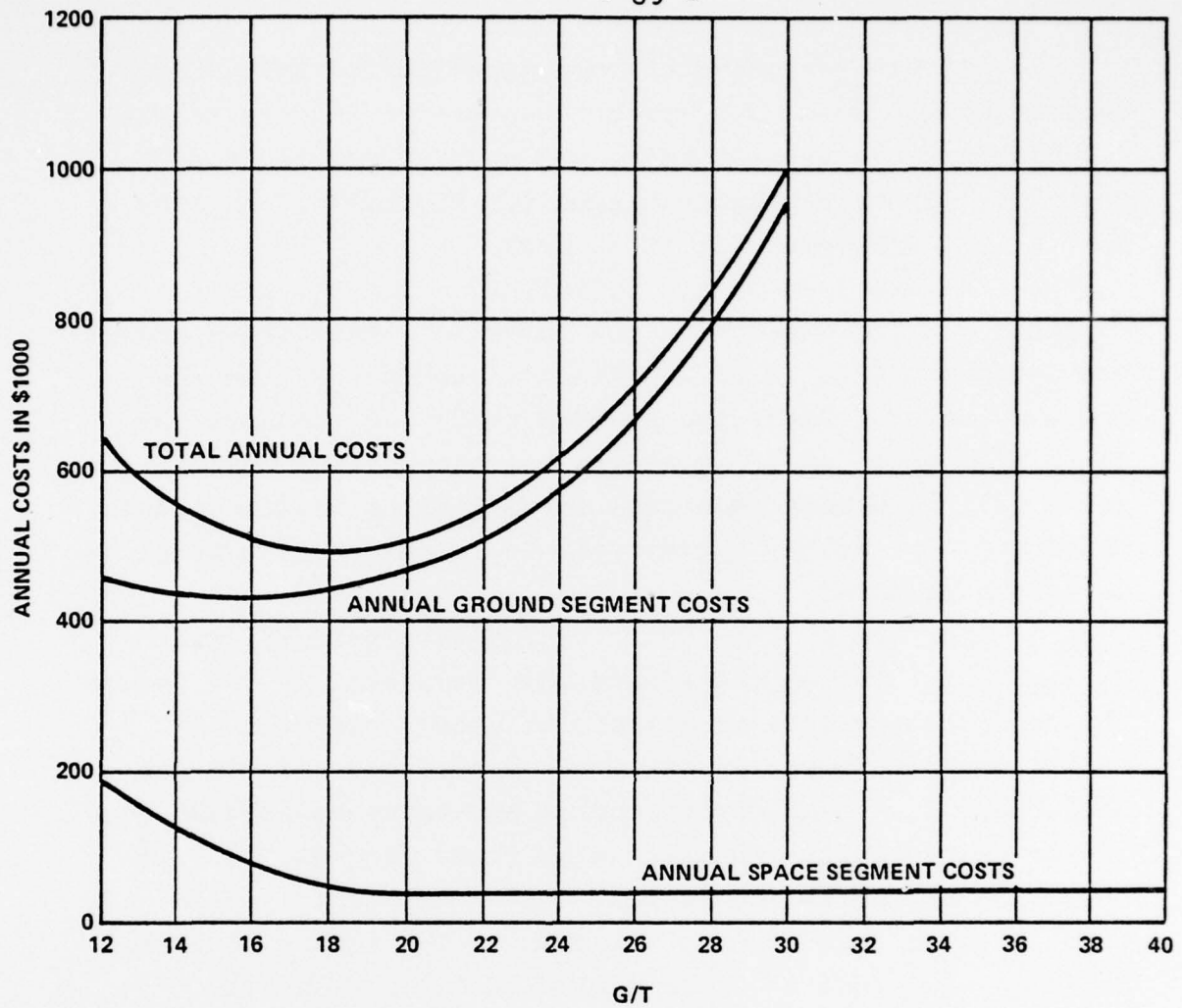


FIGURE 5-7
ANNUAL COSTS VERSUS G/T FOR
LOW CAPACITY TRAFFIC MODEL
PSK - SCPC TRANSMISSION
DOMESTIC C-BAND TRANSPONDER

Figure 5-8 shows the optimization for INTELSAT IV. Because of the lower EIRP of this satellite and the resulting higher space segment cost, the optimum G/T is 26 dB/K. Figure 5-9 shows the optimization for INTELSAT IV-A, with the optimum C/T occurring at 22 dB/K.

Figure 5-10 is the optimization for the high capacity traffic model with the domestic C-band transponder. The optimum G/T is 18 dB/K, identical to that of the low capacity model. Since the average number of channels per earth station is small in all cases, the optimum operating point will be almost identical for all three traffic models. Therefore, in further optimization only one traffic model need be considered.

For the systems optimization with DSCS II, the C-band earth station costs have been increased by 30%, since the production volume of commercial grade equipment at 7/8 GHz is lower than at 4/6 GHz. The same factor of 30% has been used for K-band earth station equipment to account for the lower production quantities at these frequencies. It should be noted that commercial grade equipment is used throughout in this cost optimization. The impact of using Mil Spec equipment has been evaluated in section 8.1.

Figure 5-11 shows the optimization for DSCS II global beam. The optimum G/T is 26 dB/K, similar to that of INTELSAT IV global beam.

The curves of Figure 5-7 through 5-11 provide enough information to permit scaling of optimum G/T ratios for all conditions of PSK-SCPC operation.

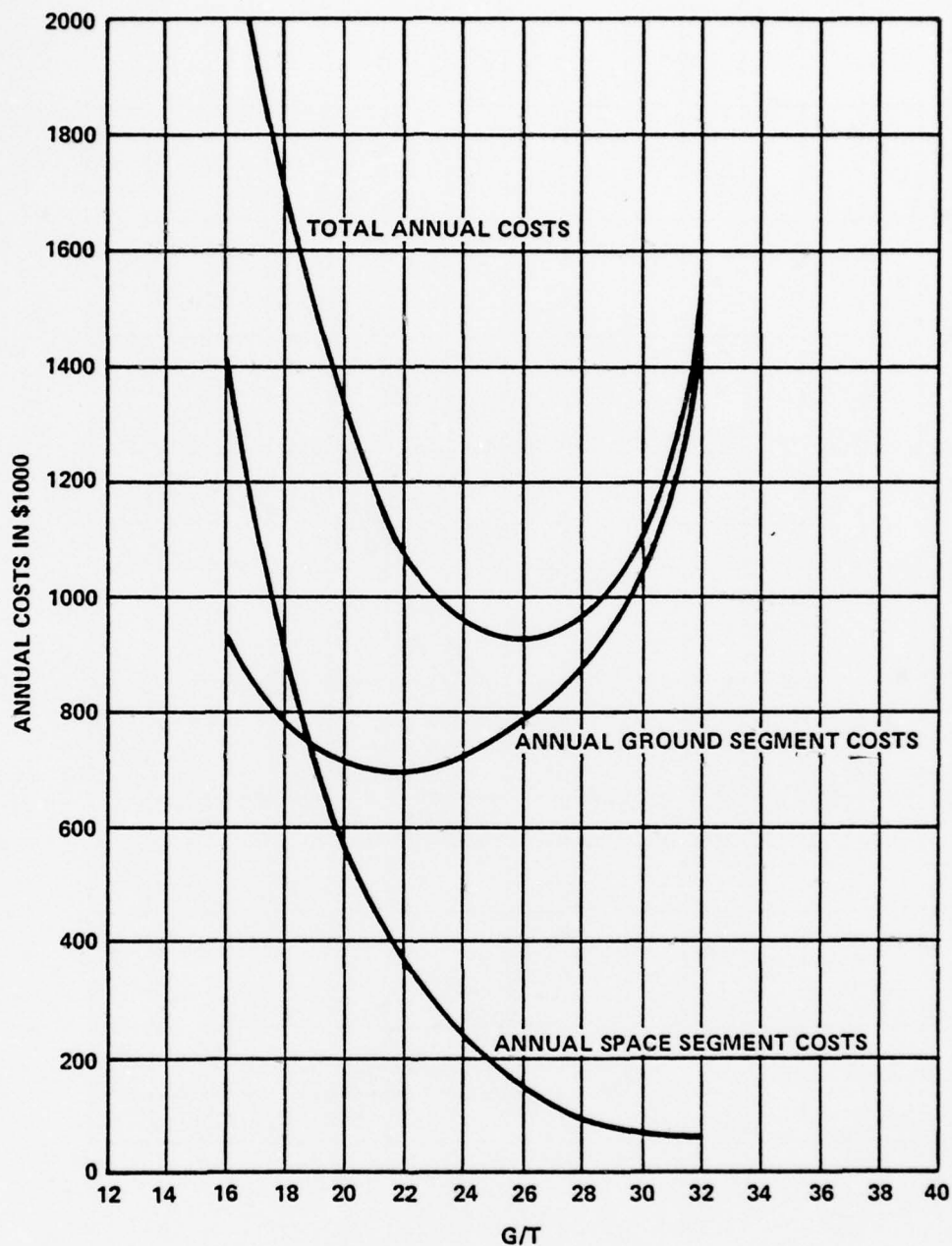


FIGURE 5-8
ANNUAL COST VERSUS G/T FOR
LOW CAPACITY TRAFFIC MODEL
PSK - SCPC TRANSMISSION
INTELSAT IV - GLOBAL BEAM TRANSPONDER

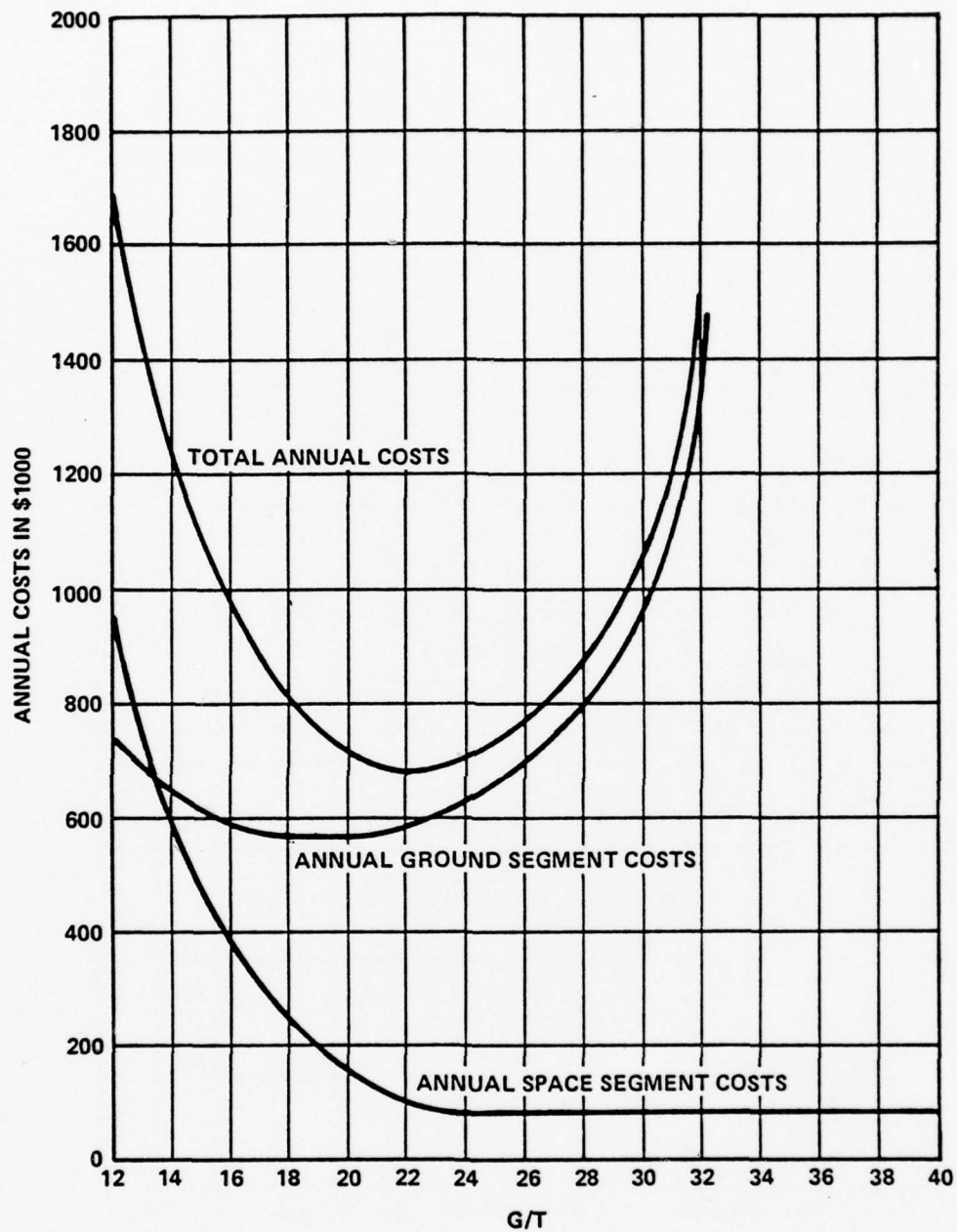


FIGURE 5-9
ANNUAL COSTS VERSUS G/T FOR
LOW CAPACITY TRAFFIC MODEL
PSK - SCPC TRANSMISSION
INTELSAT IV-A REGIONAL COVERAGE

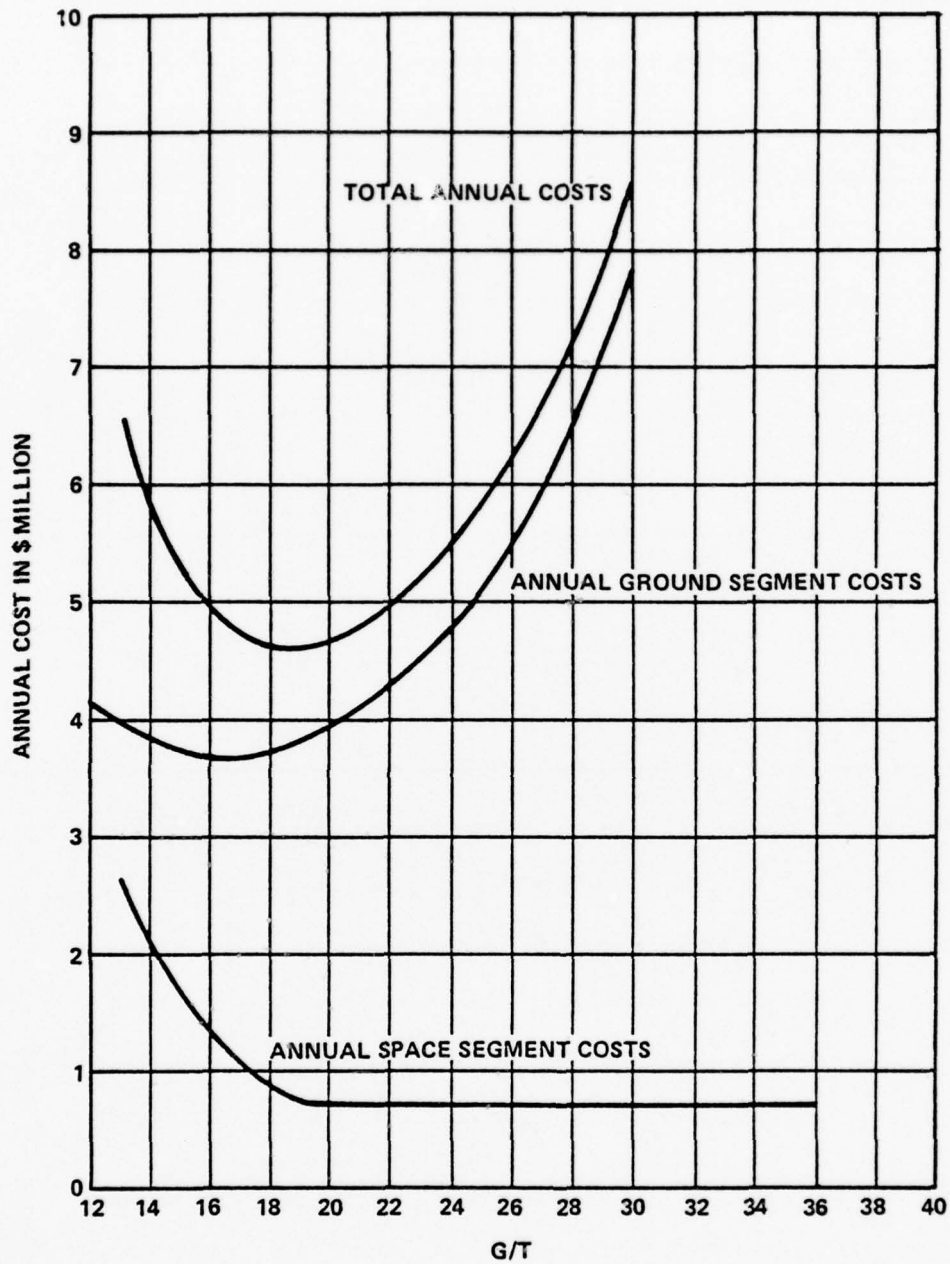


FIGURE 5-10
ANNUAL COSTS VERSUS G/T FOR
HIGH CAPACITY TRAFFIC MODEL
PSK - SCPC TRANSMISSION
DOMESTIC C-BAND TRANSPONDER

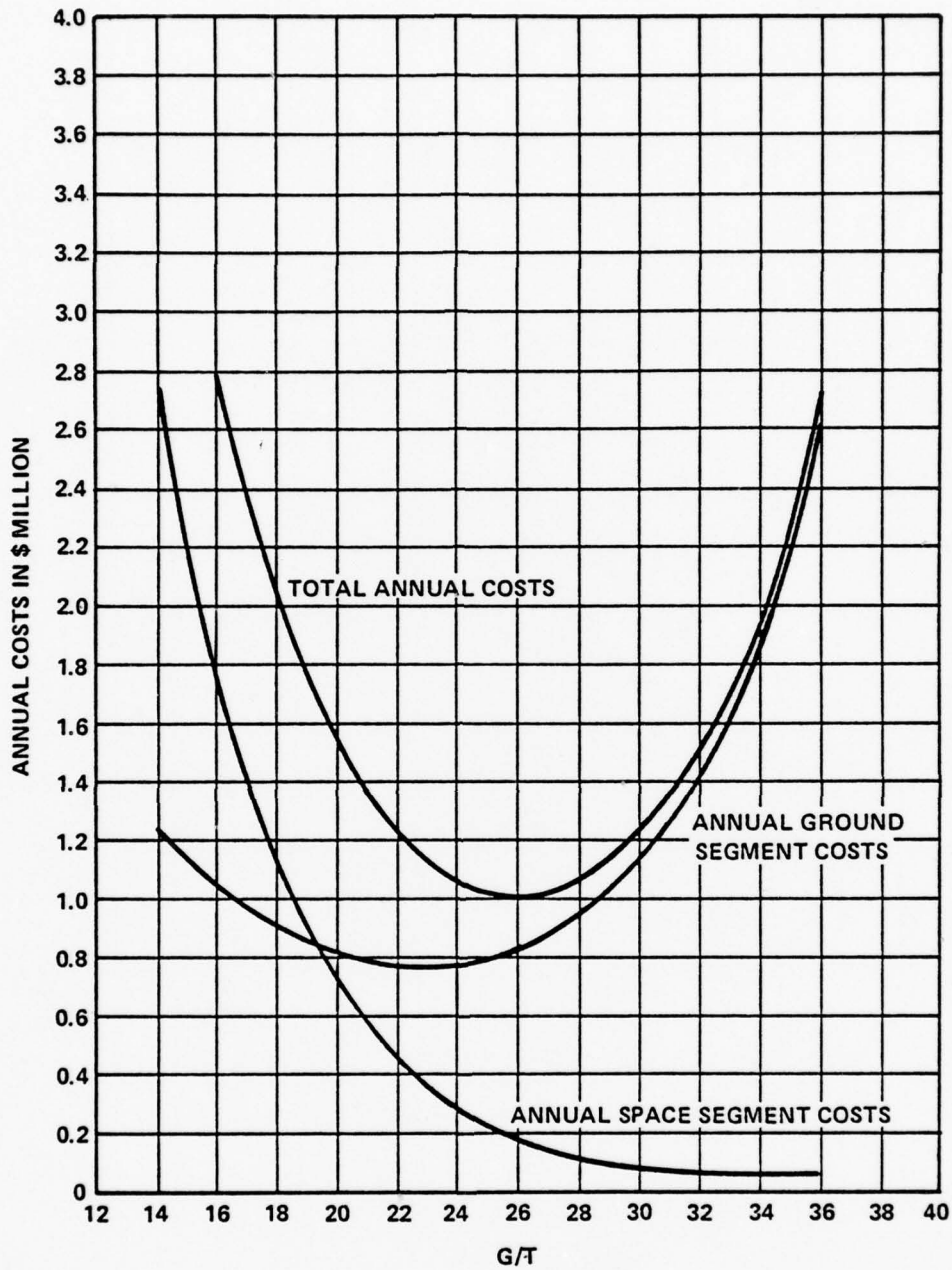


FIGURE 5-11
ANNUAL COSTS VERSUS G/T FOR
LOW CAPACITY TRAFFIC MODEL
PSK - SCPC TRANSMISSION
DSCS II, GLOBAL BEAM

5.4 SYSTEMS OPTIMIZATION FOR THE TDM-PSK-FDMA SYSTEM

In this section the optimum configuration for the TDM-PSK-FDMA system was determined for each traffic model and each satellite type.

5.4.1 Earth Station EIRP and RF Power Requirements

In the power limited region, the transponder capacities with this system are 4 dB lower than with the SCPC system. Accordingly, the average transmit power per channel is 4 dB higher than in the SCPC system. For a station with only one channel, the transmit power requirement is identical, since the SCPC transmit power requirement is 4 dB higher during carrier on condition than the calculated average power level. In the bandwidth limited operating mode, the number of channels in the system is identical and the average transmit power requirements are also identical. The resulting power requirements per channel for this system are shown in Table 5-23.

Since each earth station transmits only a single carrier, the earth station HPA does not require a back-off.

5.4.2 Incremental Systems Costs Versus G/T

The earth station EIRP requirements per channel for earth stations with only one or two channels are identical to those for SCPC transmission. For larger numbers of channels, the SCPC earth stations benefit from a reduction in average power due to the voice activity factor; however, the HPA must operate at a back-off. The TDMA-PSK-FDMA system does not use voice switching; therefore, the average power per channel is higher. However, since each earth station transmits only one carrier, the HPA can operate with less

Table 5-23
Earth Station HPA Power per Channel
for TDM-PSK-FDMA Transmission
(Power in Watts)

G/T (dB/K)	Domsat C-Band	Domsat K-Band	DSCS II Global	DSCS II Spot	INTELSAT IV Global	INTELSAT IV-A Regional
12	33.9	427	--	30	--	538
14	13.6	171	1507	11	1700	214
16	6.8	68	602	3.5	847	108
18	3.0	28	239	1.0	377	48
20	1.5	10.8	95	0.25	191	25
22	0.6	4.3	38	0.09	96	12.1
24	0.3	1.8	19	0.059	53	5.9
26	0.15	0.60	7.5	0.030	28	2.3
28	0.09	0.20	3.0	0.015	14	1.2
30	0.05	0.05	1.0	0.009	5.4	0.5
32	--	0.014	0.33	0.006	1.8	0.2
34	--	0.007	0.11	--	--	--
36	--	--	0.03	--	--	--

back-off. As a result, there is little difference in HPA power requirements and therefore in earth station costs between the two systems.

However, the channel capacities of the TDMA-PSK-FDMA system are lower than those of the PSK-SCPC system, resulting in higher space segment cost allocations. Annual costs versus G/T are shown in Figures 5-12 through 5-16.

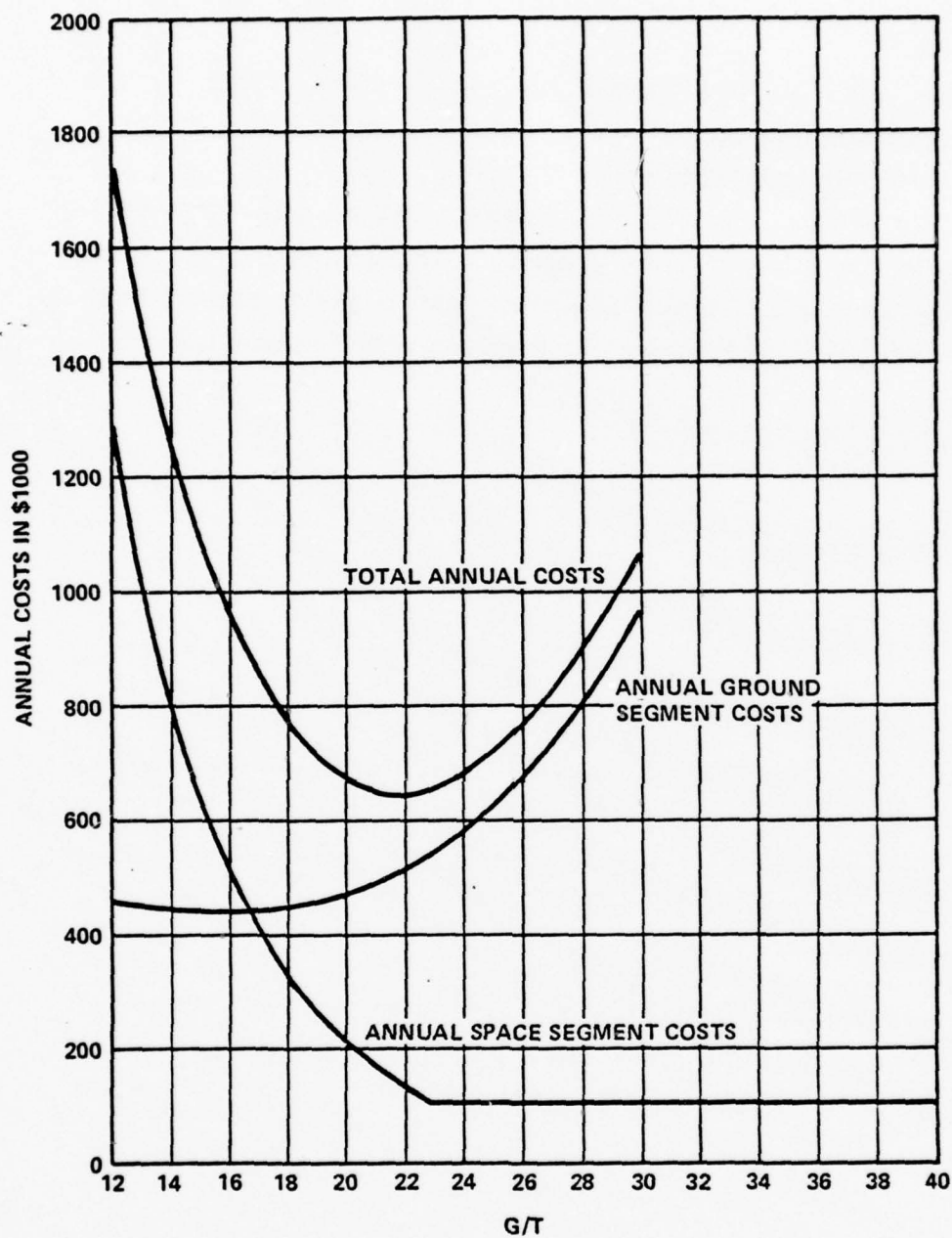


FIGURE 5-12
ANNUAL COSTS VERSUS G/T FOR
LOW CAPACITY TRAFFIC MODEL
TDM-PSK-FDMA TRANSMISSION
DOMESTIC C-BAND TRANSPONDER

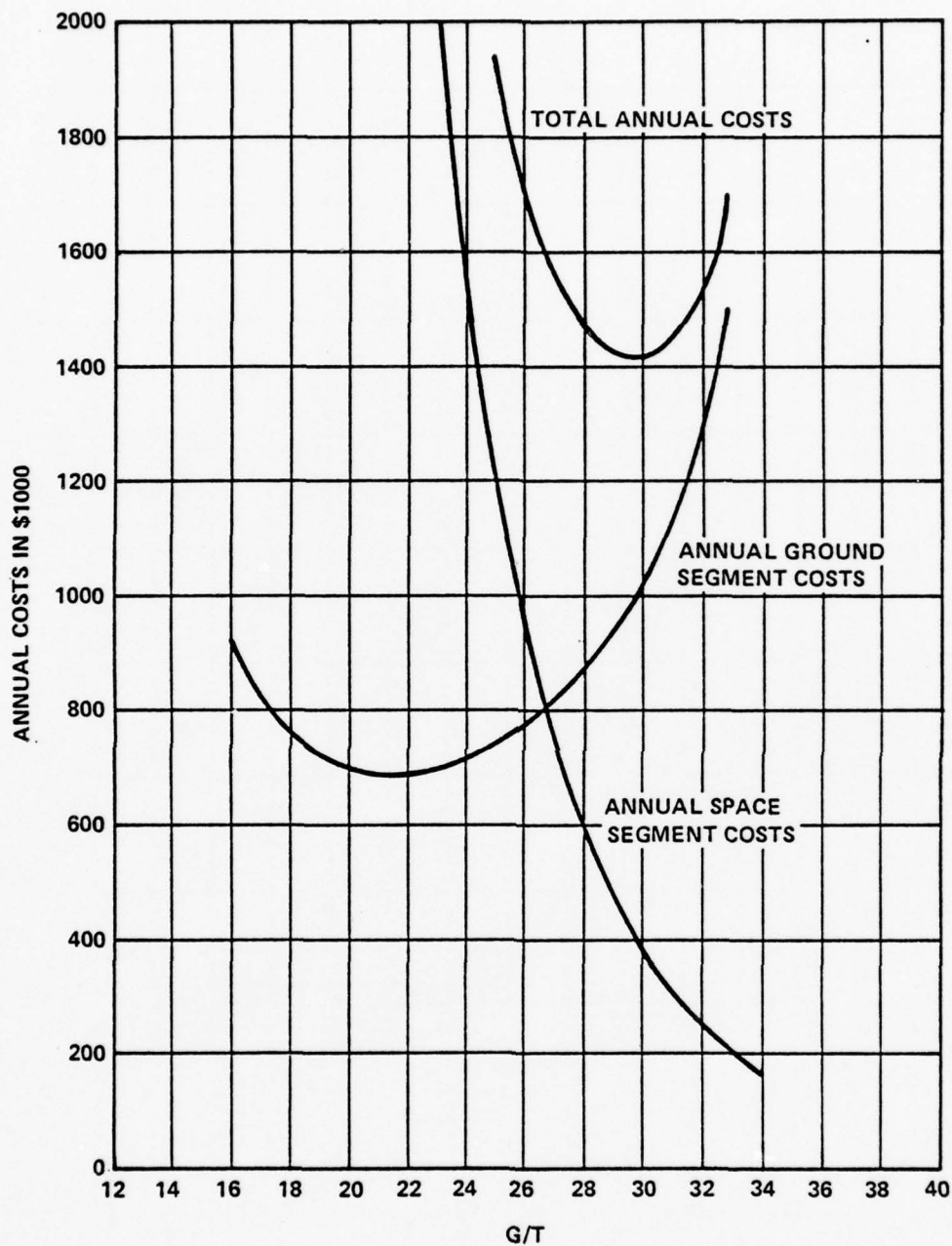


FIGURE 5-13
ANNUAL COSTS VERSUS G/T FOR
LOW CAPACITY TRAFFIC MODEL
TDM-PSK-FDMA TRANSMISSION
INTELSAT IV - GLOBAL BEAM TRANSPONDER

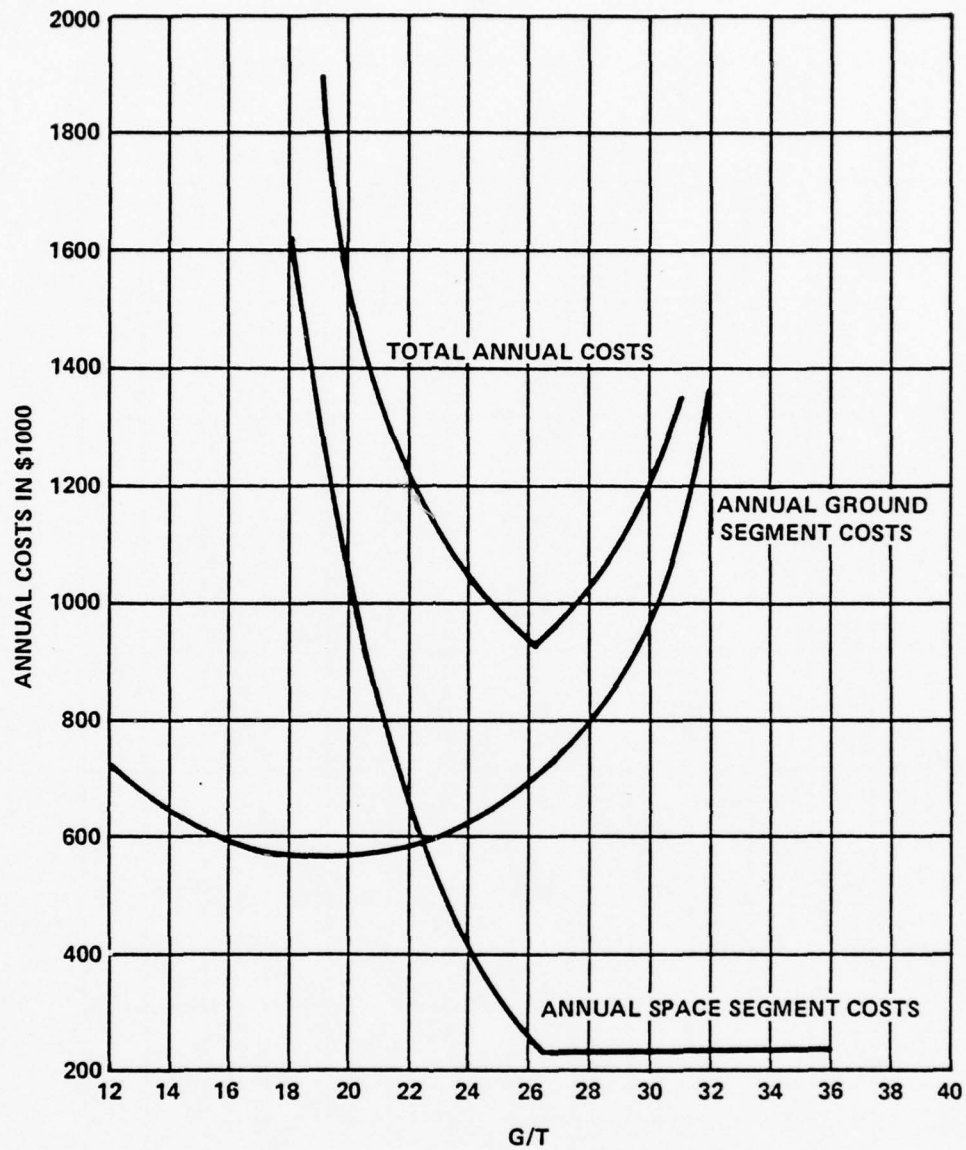


FIGURE 5-14
ANNUAL COSTS VERSUS G/T FOR
LOW CAPACITY TRAFFIC MODEL
TDM-PSK-FDMA TRANSMISSION
INTELSAT IV-A REGIONAL COVERAGE

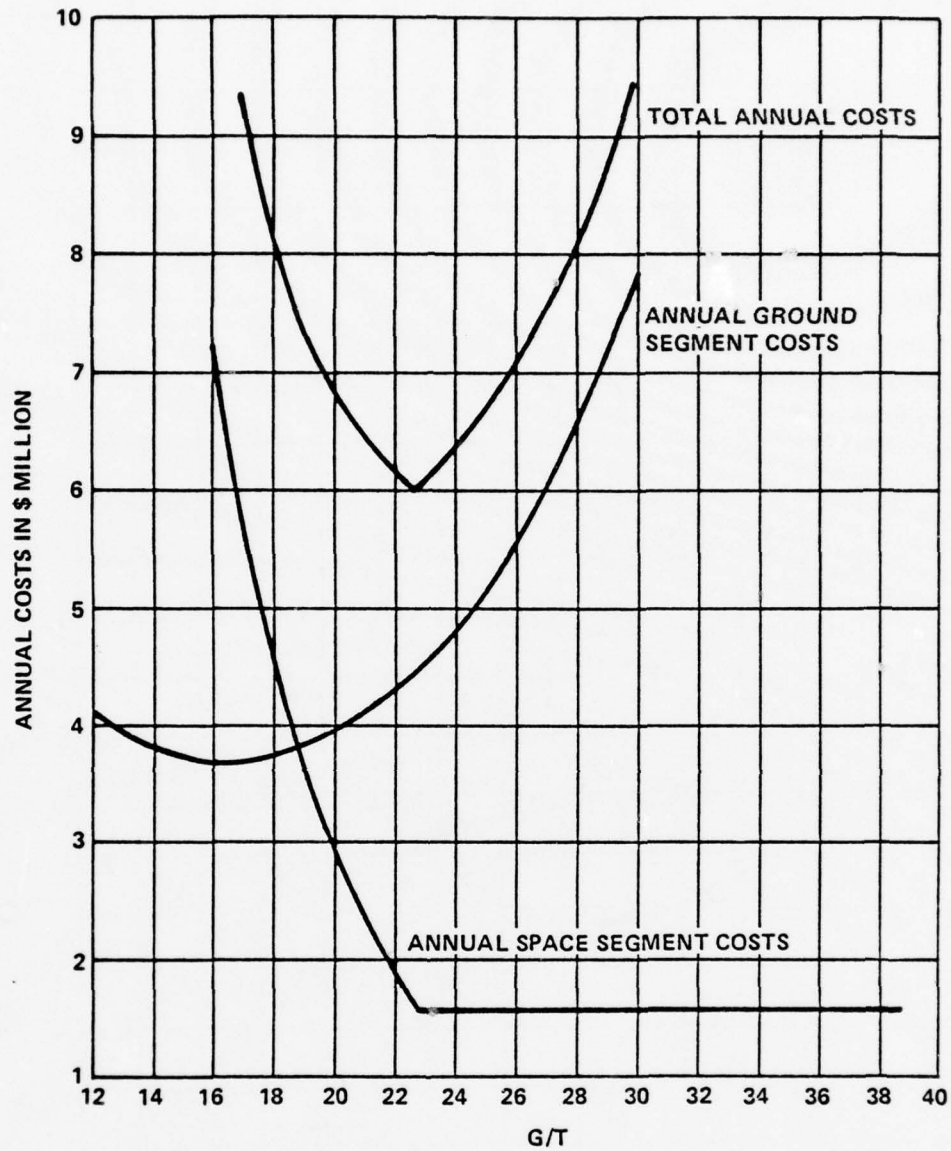


FIGURE 5-15

ANNUAL COSTS VERSUS G/T FOR
HIGH CAPACITY TRAFFIC MODEL
TDM-PSK-FDMA TRANSMISSION
DOMESTIC C-BAND TRANSPONDER

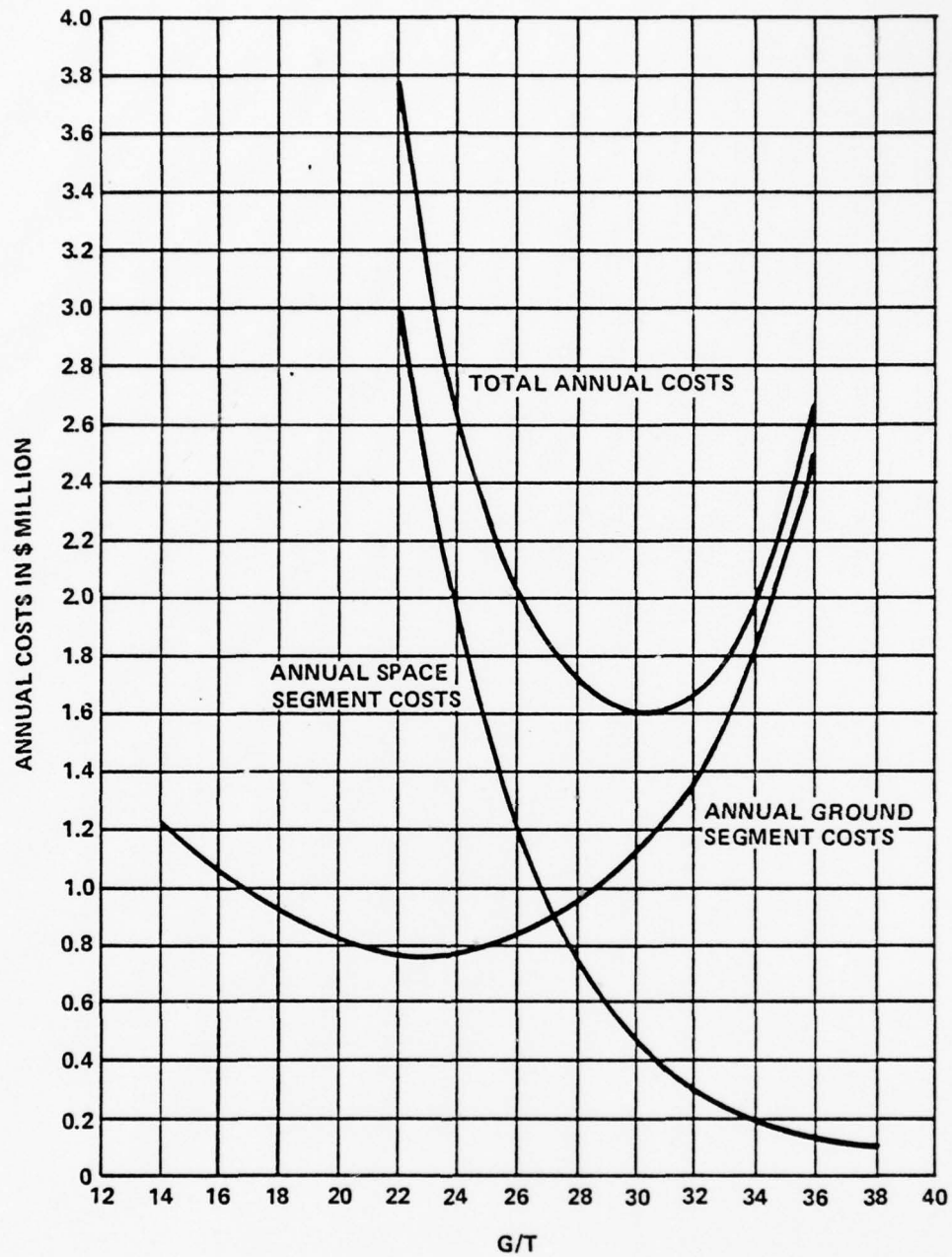


FIGURE 5-16

ANNUAL COSTS VERSUS G/T FOR
LOW CAPACITY TRAFFIC MODEL
TDM-PSK-FDMA TRANSMISSION
DCSC II, GLOBAL BEAM

5.5 SYSTEMS OPTIMIZATION FOR TDMA OPERATION

In this section, the optimum configurations for the TDMA system have been determined for each traffic model and each satellite type. Three sub-cases of TDMA operation have been considered:

- (a) Operation at maximum achievable bit rate. In this case, the receive G/T and transmit EIRP of the earth station have been chosen so as to provide adequate margins for TDMA operation at the maximum achievable bit-rate. It is assumed that the TDMA time frame is shared with other users, since the requirements for the three traffic models are not sufficient to load a full transponder at maximum bit rate. Space segment costs for each traffic model were pro-rated in accordance with the fractional transponder capacity used.
- (b) Operation at the bit rate corresponding to the traffic requirements. In this case, the receive G/T and the transmit EIRP for each earth station were adjusted to provide adequate margins for TDMA operation at the bit rate that corresponds to the traffic requirement of each traffic model. The total transponder cost is allocated to the service, since no other use of the transponder is made. The transponder operates in a backed-off single carrier mode, without intermodulation.
- (c) Transponder shared with other services. This case is identical to that of (b) above, except that the transponder is shared with other services. This

reduces the space segment cost allocation, but results in operation in an intermodulation environment.

5.5.1 Calculation of Earth Station Transmit Power Requirements

- (a) Operation at maximum achievable bit rate. Required Receive G/T and transmit power are calculated as follows:

$$\left(\frac{C}{N}\right)_T = \frac{E_b}{N_o} + 10 \log \frac{R}{BW} + M_s + M_I$$

where:

$\left(\frac{C}{N}\right)_T$ = total carrier-to-noise ratio

$\frac{E_b}{N_o}$ = energy per bit-to-noise density ratio at threshold, 6 dB for BER = 10^{-2}

R = maximum bit rate per transponder,
R = BW · 0.87

BW = IF bandwidth, equals transponder bandwidth

M_s = system margin, assumed to be 5 dB at 4 GHz,
6.5 dB at 7.5 GHz and 8 dB at 12 GHz

M_I = additional margin for intersymbol distortion due to HPA and satellite nonlinearities, assumed to be 3 dB

$\left(\frac{C}{N}\right)_T$ = 13.4 dB at 4 GHz
14.9 dB at 7.5 GHz
16.4 dB at 12 GHz

$$\left(\frac{C}{N}\right)_T = \frac{1}{\frac{1}{\left(\frac{C}{N}\right)_u} + \frac{1}{\left(\frac{C}{N}\right)_D}}$$

$$\left(\frac{C}{N}\right)_u = W_s - G_m^2 - BO_I + \left(\frac{G}{T}\right)_s - k - 10 \log BW$$

$$\left(\frac{C}{N}\right)_D = EIRP_s - BO_O - PL_D + \left(\frac{G}{T}\right)_E - k - 10 \log BW$$

where:

BO_I = transponder input back-off, 4 dB

BO_O = transponder output back-off, 0.8 dB

$n = (R/16,000) \times 0.95$

= number of channels

$$P_T = W_s - G_T + P_L - G_m^2 - BO_I$$

Using these formulas, the transmission characteristics for the six satellite types under investigation have been calculated. They are shown in Table 5-24.

- (b) Operation at the bit rate corresponding to the traffic requirements. From Table 5-24 it was found that the uplink noise contribution is 1 dB or less. The link calculations can therefore be simplified by calculating only downlink C/N and adding 1 dB of uplink contribution to obtain total C/N. In the power limited mode of operation, the required C/N_o is given by:

Table 5-24
TDMA Link Performance - Maximum Bit Rate

	Satellite Type					
	DSCS II Global Beam (105 dB Gain)	DSCS II Spot Beam (105 dB Gain)	Domsat C-Band	Domsat K-Band	INTELSAT IV Global	INTELSAT IV-A Regional
W_s (dBW/m ²)	-68*	-84*	-84	-73	-73	-75
$(G/T)_s$ (dB/K)	-19	-3	-6	-6	-18	-11.6
BW (MHz)	50	50	36	54	36	36
$(C/N)_u$ (dB)	21.1	21.1	23	23.9	21	25.4
$(C/N)_D$ (dB)	15.8	15.8	13.8	17.1	14.1	13.7
EIRP _s (dBW)	28	43	33	38	22	29
PL _D (dB)	201.7	201.7	196.2	205.7	196.2	196.2
$(G/T)_E$ (dB/K)	38.7	23.7	24.8	34.3	36.1	28.7
R (Mb/s)	43.5	43.5	31.3	47.0	31.3	31.3
n	2580	2580	1860	2790	1860	1860
T (dB)	21.9	24.0	22.0	24.0	20.0	20.0
G _R (dB)	60.9	47.7	46.8	58.3	56.1	48.7
G _T (dB)	59.9	46.7	48.3	57.6	57.6	50.2
Antenna Diameter (m)	12.0	3.3	6.8	6.0	19.7	8.4
P _T (dBW)	30.8	28.0	27.4	28.1	28.1	33.5
P _T (kW)	1.2	0.63	0.55	0.65	0.65	2.2

*Derived from Technical Note No. 39-75; see section 2.1.1.

$$\frac{C}{N_O} = 10 \log R + \frac{E}{N_O} + M_S + M_I$$

or

$$\frac{C}{N_O} = 10 \log R + M_S + 9$$

C/N_O for the three traffic models and the three operating frequencies is shown in Table 5-25.

Table 5-25
 C/N_O Needed to Satisfy Traffic Requirements

Traffic Model	Low Capacity	Medium Capacity	High Capacity
Number of Channels	90	219	1100
Bit rate in Mb/s at 5% overhead	1.4	3.7	18.5
C/N_O at 4 GHz, $M_S = 5$ dB	75.5	79.7	86.7
C/N_O at 7.5 GHz, $M_S = 6.5$ dB	77.0	81.2	88.2
C/N_O at 12 GHz, $M_S = 8$ dB	78.5	82.7	89.7

$$\frac{C}{N_O} = \text{EIRP}_S - \text{BO}_O - \text{PL}_D + \left(\frac{G}{T}\right)_E - k$$

The specified C/N_O can be obtained with a range of combinations of earth station G/T and back-off.

Table 5-26 shows transmission parameters for the low capacity traffic model and all six satellite types. It was found that a TDMA system is possible with relatively small antennas and low transmit power levels by operating at a transponder output back-off of 10 dB. This reduces the earth station costs, but the full transponder lease rate will be charged to the system, which makes this solution unattractive.

Table 5-26
TDMA Link Performance at Bit Rate to Meet Traffic
Requirements for Low Capacity Model

	Satellite Type					
	DSCS II Global Beam	DSCS II Spot Beam	Domsat C-Band	Domsat K-Band	INTELSAT IV Global	INTELSAT IV-A Reg. Coverage
C/N_O (dB-Hz)	77.0	77.0	75.5	78.5	75.5	75.5
$(G/T)_E - B O_O$ (dB)	22.1	7.1	10.1	17.6	21.1	14.1
$(G/T)_E$ (dB/K)	32.1	17.1	20.1	27.6	31.1	24.1
$B O_O$ (dB)	10	10	10	10	10	10
$B O_I$ (dB)	16	16	16	16	16	16
G_T (dB)	55.1	42.1	44.1	51.6	51.1	46.1
Antenna Diameter (m)	7.2	2.4	5.2	3.3	9.5	6.3
P_T (dBW)	23.6	20.6	19.6	22.1	22.6	25.6
P_T (Watts)	230	120	90	165	182	360

- (c) Transponder Shared with Other Services. In this operating mode, the transponder should be driven to an output back-off of 4 to 5 dB, depending on the other services that will be carried. Uplink and intermodulation noise contributions will be similar to those of the TDM-PSK-TDMA system. For this reason, the optimum G/T ratios in the two systems will be similar. Since the TDMA system must transmit higher power levels than the TDM-PSK-TDMA system, the optimum G/T will be slightly higher for the TDMA system. However, the differences are not large enough to warrant a separate optimization.

In all TDMA applications, we have assumed that pulsed HPAs will not be available. The power rating of each HPA, therefore, corresponds to the power needed for the full bit rate of the system.

Section 6
SYSTEMS COMPARISON

Based on the optimization carried out in section 5, the three modulation systems under study can now be compared. The systems optimization was important to ensure that each modulation system is used under optimum conditions. All technical data required for the comparison have already been developed and presented in earlier sections. Based on this information, the costs for each case have been tabulated and compared.

6.1 PSK-SCPC COSTS

Tables 6-1 through 6-6 show the systems costs for PSK-SCPC transmission for each satellite and traffic model. The first step is the selection of the optimum G/T. This is determined from Figures 5-7 through 5-11. HPA power levels are taken from Table 5-20. Quantities of equipment are selected in accordance with the requirements of the traffic models, sections 2.1 and 3.1. Unit equipment costs are based on sections 4.2 and 5.2. Annual space segment costs are found in Tables 5-1 through 5-6. Total ground segment subsystem costs are multiplied by a factor of 1.5 to allow for cabinets, wiring, installation, spares and documentation. Total costs are annualized by a factor of 0.28. Thus, the factor of 0.42 can be applied to the subsystem costs to find the annual ground segment costs.

For SCPC transmission through a domestic C-band transponder, the optimum G/T is 28 dB/K. This G/T could be accomplished with an earth station antenna diameter of approximately 4.5 meters. Such an antenna may not meet the FCC requirements for sidelobe response; therefore, a G/T of 20 dB/K has been selected in the model. This G/T would be

Modulation System: PSK-SCPC
 Satellite Type: Domestic C-Band
 Earth Station G/T: 20 dB/K
 Table 6-1
 System Costs
 (\$1000)
 HPA: 0.8 W/Ch. Av.
 = -1 dBW/Ch. Av.

Traffic Model	Unit Cost	Low Capacity		Medium Capacity		High Capacity	
		Quantity	Cost	Quantity	Cost	Quantity	Cost
Antenna & INR	30	26	780	10	300	211	6330
HPA							
1 Ch. 3	10	10	100	-	-	100	1000
2 Ch. 9	12	10	120	-	-	-	-
6 Ch. 14	15	5	75	-	-	100	1500
20 Ch. 17	18	1	18	10	180	10	180
200 Ch. 26	28	-	-	-	-	1	28
Up-Converter	11	26	286	10	110	211	2321
Down-Converter	11	26	286	10	110	211	2321
Common Equipment-Cent.	105	1	105	1	105	1	105
" "-Rem.	12	25	300	9	108	210	2520
Channel Units	6	80	480	219	1314	1100	6600
Total Ground Segment Subsystem Costs			2550		2227		22905
Annual Ground Segment			1071		935		9620
Annual Space Segment			40		211		719
TOTAL ANNUAL COSTS			1111		1146		10339

Table 6-2
 Modulation System: PSK-SCPC
 Satellite Type: IS-IV Global Beam
 Earth Station G/T: 26 dB/K
 System Costs (\$1000)
 HPA: 11 W/Ch. Av.
 = 10.4 dBW/Ch. Av.

Traffic Model	Unit Cost	Low Capacity		Medium Capacity		High Capacity	
		Quantity	Cost	Quantity	Cost	Quantity	Cost
Antenna & LNR	50	26	1300	10	500	211	10550
HPA							
1 Ch. 14.4	16	10	160	-	-	100	1600
2 Ch. 20.4	21	10	210	-	-	-	-
6 Ch. 25.4	27	5	135	-	-	100	2700
20 Ch. 28.4	32	1	32	10	320	10	320
200 Ch. 37.4	50	-	-	-	-	1	50
Up-Converter	11	26	286	10	110	211	2321
Down-Converter	11	26	286	10	110	211	2321
Common Equipment-Cent.	105	1	105	1	105	1	105
Common Equipment-Rem.	12	25	300	9	108	210	2520
Channel Units	6	80	480	219	1314	1100	6600
Total Ground Segment Subsystem Costs			3294		2567		29087
Annual Ground Segment			1384		1078		12216
Annual Space Segment			141		740		2520
TOTAL ANNUAL COSTS			1524		1818		14736

Table 6-3
System Costs
(\$1000)

Modulation System: PSK-SCPC
Satellite Type: IS-IVA Regional
Earth Station G/T: 22 dB/K

HPA: 4.8 W/Ch. Av.
= 6.8 dBW/Ch. Av.

Traffic Model	Unit Cost	Low Capacity		Medium Capacity		High Capacity	
		Quantity	Cost	Quantity	Cost	Quantity	Cost
Antenna & LNR	35	26	910	10	350	211	7385
HPA							
1 Ch. 10.8	12	10	120	-	-	100	1200
2 Ch. 16.8	18	10	180	-	-	-	-
6 Ch. 21.8	22	5	110	-	-	100	2200
20 Ch. 24.8	26	1	26	10	260	10	260
200 Ch. 33.8	41	-	-	-	-	1	41
Up-Converter	11	26	286	10	110	211	2321
Down-Converter	11	26	286	10	110	211	2321
Common Equipment-Cent.	105	1	105	1	105	1	105
Common Equipment-Rem.	12	25	300	9	108	210	2520
Channel Units	6	80	480	219	1314	1100	6600
Total Ground Segment Subsystem Costs			2997		2357		24953
Annual Ground Segment			1175		990		10480
Annual Space Segment			94		494		1684
TOTAL ANNUAL COSTS			1269		1484		12164

Modulation System: PSK-SCPC
 Satellite Type: DSCS-II, Global Beam
 Earth Station G/T: 26 dB/K

Table 6-4
 System Costs
 (\$1000)

HPA: 3 W/Ch. Av.
 = 4.8 dBW/Ch. Av.

Traffic Model	Unit Cost	Low Capacity		Medium Capacity		High Capacity	
		Quantity	Cost	Quantity	Cost	Quantity	Cost
Antenna & LNR	65	26	1690	10	650	211	13715
HPA							
1 Ch. 8.8	16	10	160	-	-	100	1600
2 Ch. 14.8	21	10	210	-	-	-	-
6 Ch. 19.8	26	5	130	-	-	100	2600
20 Ch. 22.8	29	1	29	10	290	10	290
200 Ch. 31.8	48	-	-	-	-	1	48
Up-Converter	14	26	364	10	140	211	2954
Down-Converter	14	26	364	10	140	211	2954
Common Equipment-Cent.	105	1	105	1	105	1	105
Common Equipment-Rem.	12	25	300	9	108	210	2520
Channel Units	6	80	480	219	1314	1100	6600
Total Ground Segment Subsystem Costs			3832		2747		33386
Annual Ground Segment			1609		1154		14022
Annual Space Segment			177		931		3000
TOTAL ANNUAL COSTS			1786		2085		17022

Table 6-5
 Modulation System: PSK-SCPC
 Satellite Type: DSCS II, Spot Beam
 Earth Station G/T: 18 dB/K
 System Costs (\$1000)
 HPA: 0.5 W/Ch. Av.
 = -3 dBW/Ch. Av.

Traffic Model	Unit Cost	Low Capacity		Medium Capacity		High Capacity	
		Quantity	Cost	Quantity	Cost	Quantity	Cost
Antenna & LNR	34	26	884	10	340	211	7174
HPA							
1 Ch.	13	10	-	-	-	100	-
2 Ch.	14	10	-	-	-	-	-
6 Ch.	18	5	-	-	-	100	-
20 Ch.	21	1	-	10	-	10	-
200 Ch.	32	-	-	-	-	1	-
Up-Converter	11	26	364	10	140	211	2954
Down-Converter	11	26	364	10	140	211	2954
Common Equipment-Cent.	105	1	105	1	105	1	105
Common Equipment-Rem.	12	25	300	9	108	210	2520
Channel Units	6	80	480	219	1314	1100	6600
Total Ground Segment Subsystem Costs			2878		2357		25695
Annual Ground Segment			1209		990		10773
Annual Space Segment			58		304		1036
TOTAL ANNUAL COSTS			1267		1294		11809

Table 6-6
 Modulation System: PSK-SCPC
 Satellite Type: Domestic, K-Band
 Earth Station G/T: 24 dB/K
 System Costs (\$1000)
 HPA: 0.7 W/Ch. Av.
 = -1.5 dBW/Ch. Av.

Traffic Model	Unit Cost	Low Capacity		Medium Capacity		High Capacity	
		Quantity	Cost	Quantity	Cost	Quantity	Cost
Antenna & LNR	34	26	884	10	340	211	7174
HPA							
1 Ch. 2.5	13	10	130	-	-	100	1300
2 Ch. 8.5	14	10	140	-	-	-	-
6 Ch. 13.5	20	5	100	-	-	100	2000
20 Ch. 16.5	22	1	22	10	220	10	220
200 Ch. 25.5	36	-	-	-	-	1	36
Up-Converter	14	26	364	10	140	211	2954
Down-Converter	14	26	364	10	140	211	2954
Common Equipment-Cent.	105	1	105	1	105	1	105
Common Equipment-Rem.	12	25	300	9	108	210	2520
Channel Units	6	80	480	219	1314	1100	6600
Total Ground Segment Subsystem Costs			2889		2367		25863
Annual Ground Segment			1213		994		10862
Annual Space Segment			133		698		2379
TOTAL ANNUAL COSTS			1346		1692		13241

achieved with an antenna with approximately 5.3 meters diameter which meets the sidelobe requirements.

For a small number of channels, the HPA cannot benefit from the full voice activity advantage. The power rating of the HPA is therefore based on a higher power level than the average power. In addition, the HPA must operate at a back-off for all cases except when a single channel per earth station is transmitted. The following values have been used in determining the HPA power requirement:

Channels per Earth Station	Ratio of Peak to Average Power (dB)	HPA Output Back-Off (dB)	HPS Power Rating Relative to Average Power per Channel (dB)
1	4	0	4
2	4	3	10
6	3	4	15
20	1	4	18
200	0	4	27

6.2 TDM-PSK-FDMA SYSTEM COSTS

Tables 6-7 through 6-12 show the systems costs for the TDM-PSK-FDMA system for each satellite and traffic model. The optimum G/T was selected from Figures 5-12 through 5-16. Because of the lower transponder capacity and therefore higher space segment cost, this G/T is higher than that for SCPC transmission. Therefore, the antenna costs are higher than with SCPC transmission.

Table 6-13 shows the baseband equipment costs that apply for TDM-PSK-FDMA transmission. Each station needs a receive chain for each transmission link. To keep the equipment requirements within practical limits, it was not possible to provide full interconnectivity between all

Modulation System: TDM-PSK-FDMA
Satellite Type: Domestic C-Band
Earth Station G/T: 22 dB/K

Table 6-7
System Costs
(\$1000)

HPA: 0.6 W/Ch. Av.
= -2.2 dBW/Ch. Av.

Traffic Model	Unit Cost	Low Capacity		Medium Capacity		High Capacity	
		Quantity	Cost	Quantity	Cost	Quantity	Cost
Antenna & LNR	35	26	910	10	350	211	7385
HPA Power dBW							
1 Ch. -2.2	10	10	100	-	-	100	1000
2 Ch. 0.8	10	10	100	-	-	-	-
6 Ch. 5.6	10	5	50	-	-	100	1000
20 Ch. 10.8	13	1	13	10	130	10	130
200 Ch. 20.8	22	-	-	-	-	1	22
Up-Converter	11	26	286	10	110	211	2321
Down-Converter	11	170	1870	90	990	2510	27610
Baseband Equipment (see Table 6-13)			6371		3706		85310
Total Ground Segment Subsystem Costs			9700		5286		124778
Annual Ground Segment			4074		2220		52407
Annual Space Segment			130		356		1788
TOTAL ANNUAL COSTS			4204		2576		54195

Modulation System: TDM-PSK-FDMA
Satellite Type: IS-IV, Global Beam
Earth Station G/T: 30 dB/K

Table 6-8
System Costs
(\$1000)

HPA: 5.4 W/Ch. Av.
= 7.3 dBW/Ch. Av.

Traffic Model	Unit Cost	Low Capacity		Medium Capacity		High Capacity	
		Quantity	Cost	Quantity	Cost	Quantity	Cost
Antenna & LNR	78	26	2028	10	780	211	
HPA							
1 Ch. 7.3	11	10	110	-	-	100	
2 Ch. 10.3	13	10	130	-	-	-	
6 Ch. 15.1	16	5	80	-	-	100	
20 Ch. 20.3	21	1	21	10	210	10	
200 Ch. 30.3	35	-	-	-	-	1	
Up-Converter	11	26	286	10	110	211	
Down-Converter	11	170	1870	90	990	2510	
Baseband Equipment (see Table 6-13)			6371		3706		85310
Total Ground Segment Subsystem Costs			10896		5796		
Annual Ground Segment			4576		2434		
Annual Space Segment			389		1066		
TOTAL ANNUAL COSTS			4965		3500		

Table 6-9
 Modulation System: TDM-PSK-FDMA
 Satellite Type: IS-IVA, Regional
 Earth Station G/T: 26 dB/K
 System Costs (\$1000)
 HPA: 2.3 W/Ch. Av.
 = 3.6 dBW/Ch. Av.

Traffic Model	Unit Cost	Low Capacity		Medium Capacity		High Capacity	
		Quantity	Cost	Quantity	Cost	Quantity	Cost
Antenna & LNR	50	26	1300	10	500	211	
HPA							
1 Ch. 3.6	10	10	100	-	-	100	
2 Ch. 6.6	10	10	100	-	-	-	
6 Ch. 11.0	13	5	65	-	-	100	
20 Ch. 16.6	17	1	17	10	170	10	
200 Ch. 26.6	29					1	
Up-Converter	11	26	286	10	110	211	
Down-Converter	11	170	1870	90	990	2510	
Baseband Equipment (see Table 6-13)			6371		3706		85310
Total Ground Segment Subsystem Costs			10109		5476		
Annual Ground Segment			4246		2300		
Annual Space Segment			259		712		
TOTAL ANNUAL COSTS			4505		2712		

Modulation System: TDM-PSK-FDMA
 Satellite Type: DSCS II, Global Beam
 Earth Station G/T: 30 dB/K

Table 6-10
 System Costs
 (\$1000)

HPA: 1 W/Ch. Av.
 = 0 dBW/Ch. Av.

Traffic Model	Unit Cost	Low Capacity		Medium Capacity		High Capacity	
		Quantity	Cost	Quantity	Cost	Quantity	Cost
Antenna & LNR	66	26	1716	10	660	211	
HPA							
1 Ch. 0	13	10	130	-	-	100	
2 Ch. 3	13	10	130	-	-	-	
6 Ch. 7.8	14	5	70	-	-	100	
20 Ch. 13	18	1	18	10	180	10	
200 Ch. 23	31						
Up-Converter	14	26	364	10	140	211	
Down-Converter	14	170	2380	90	1260	2510	
Baseband Equipment (see Table 6-13)			6371		3706		85310
Total Ground Segment Subsystem Costs			11179		5946		
Annual Ground Segment			4695		2497		
Annual Space Segment			489		1342		
TOTAL ANNUAL COSTS			5184		3839		

Table 6-11
 Modulation System: TDM-PSK-FDMA
 Satellite Type: DSCS II, Spot Beam
 Earth Station G/T: 22 dB/K
 System Costs (\$1000)
 HPA: 0.1 W-Ch. Av.
 = -10 dBW/Ch. Av.

Traffic Model	Unit Cost	Low Capacity		Medium Capacity		High Capacity	
		Quantity	Cost	Quantity	Cost	Quantity	Cost
Antenna & LNR		26	1386	10	530	211	
HPA							
1 Ch. -10	13	10	130	-	-	100	
2 Ch. -7	13	10	130	-	-	-	
6 Ch. -2	13	5	85	-	-	100	
20 Ch. 3	13	1	13	10	130	10	
200 Ch. 13	18	-	-	-	-	1	
Up-Converter	14	26	364	10	140	211	
Down-Converter	14	170	2380	90	1260	2510	
Baseband Equipment (see Table 6-13)			6371		3706		85310
Total Ground Segment Subsystem Costs			10859		5766		
Annual Ground Segment			4561		2422		
Annual Space Segment			160		438		
TOTAL ANNUAL COSTS			4721		2860		

Modulation System: TDM-PSK-FDMA
 Satellite Type: Domestic K-Band
 Earth Station G/T: 28 dB/K
 HPA: 0.2 W/Ch. Av.
 System Costs (\$1000)

Table 6-12

Traffic Model	Unit Cost	Low Capacity		Medium Capacity		High Capacity	
		Quantity	Cost	Quantity	Cost	Quantity	Cost
Antenna & LNR	51	26	1326	10	510	211	
HPA							
1 Ch. -7	13	10	130	-	-	100	
2 Ch. -4	13	10	130	-	-	-	
6 Ch. 0	13	5	65	-	-	100	
20 Ch. 6	13	1	13	10	130	10	
200 Ch. 17	23	-	-	-	-	1	
Up-Converter	14	26	364	10	140	211	
Down-Converter	14	170	2380	90	1260	2510	
Baseband Equipment (see Table 6-13)			6371		3706		85310
Total Ground Segment Subsystem Costs			10779		5746		
Annual Ground Segment			4527		2413		
Annual Space Segment			367		1006		
TOTAL ANNUAL COSTS			4894		3419		

Table 6-13
TDM-PSK-FDMA System
Baseband Equipment Costs

	Unit Cost	Low Capacity		Medium Capacity		High Capacity	
		Quantity	Cost	Quantity	Cost	Quantity	Cost
Central Station							
Transmit Link	45	1	45	1	45	1	45
Receive Link	29	25	725	9	261	210	6090
Common Equipment	55	1	55	1	55	1	55
Remote Station							
Transmit Link	20	25	500	9	180	210	4200
Receive Link	29	145	4205	81	2349	2300	66700
Common Equipment	25	24	625	9	225	210	5250
Transmit Channels	1.0	80	80	219	219	1100	1100
Receive Channels	1.7	80	136	219	372	1100	1870
TOTAL			6371		3706		85310

earth stations. For the low capacity and the high capacity models, the connectivity between stations type A, B, C and D was limited to that shown in section 3.1.2. For the medium capacity model, full interconnectivity was assumed.

Even with the limited interconnectivity, the high capacity model requires baseband equipment in the amount of \$83 million, compared to less than \$10 million in the case of SCPC. The former case is therefore not practical and has been shown only on Table 6-7 for reference.

TDM-PSK-FDMA transmission results in higher costs than SCPC transmission in all cases examined. Antenna costs are higher, more down-converters are required, baseband equipment costs are higher and space segment costs are higher.

6.3 TDMA SYSTEM COSTS

Tables 6-14 through 6-19 show the systems costs for the conventional TDMA system, where the total bandwidth and power of the transponder is used for TDMA transmission. Since the traffic models always require less than the full bit rate of the transponder in bandwidth limited operation, it was assumed that the TDMA frame would be shared with other users and that only the pro-rated portion of the transponder lease rate would be applied.

Modulation System: TDMA
 Satellite Type: Domestic, C-Band
 Earth Station G/T: 25 dB/K

Table 6-14
 System Costs
 (\$1000)

HPA: 550 W = 27.4 dBW

Traffic Model	Unit Cost	Low Capacity		Medium Capacity		High Capacity	
		Quantity	Cost	Quantity	Cost	Quantity	Cost
Antenna & LNR	46	26	1196	10	460	211	9706
HPA	30	26	780	10	300	211	6330
Up-Converter	11	26	286	10	110	211	2321
Down-Converter	11	26	286	10	110	211	2321
Common Equip.-Cent.	340	1	340	1	340	1	340
Common Equip.-Remote	124	25	3100	9	1116	210	26040
Channel Units	2.4	80	192	219	526	1100	2640
Total Ground Segment Subsystem Costs			6180		2962		49698
Annual Ground Segment			2596		1244		20873
Annual Space Segment			86		235		1183
TOTAL ANNUAL COSTS			2682		1479		22056

Modulation System: TDMA
 Satellite Type: IS IV, Global Beam
 Earth Station G/T: 36 dB/K
 Table 6-15
 System Costs
 (\$1000)
 HPA: 650 W = 28.1 dBW

Traffic Model	Unit Cost	Low Capacity		Medium Capacity		High Capacity	
		Quantity	Cost	Quantity	Cost	Quantity	Cost
Antenna & LNR	554	26	14404	10	5540	211	116894
HPA	32	26	832	10	320	211	6752
Up-Converter	11	26	286	10	110	211	2321
Down-Converter	11	26	286	10	110	211	2321
Common Equip.-Cent.	340	1	340	1	340	1	340
Common Equip.-Remote	124	25	3100	9	1116	210	26040
Channel Units	2.4	80	192	219	526	1100	2640
Total Ground Segment Subsystem Costs			19440		8062		157308
Annual Ground Segment			8165		3386		66069
Annual Space Segment			129		353		1774
TOTAL ANNUAL COSTS			8294		3738		67843

Modulation System: TDMA
 Satellite Type: IS-IVA, Regional
 Earth Station G/T: 29 dB/K

Table 6-16
 System Costs
 (\$1000)

HPA: 2200 W = 33.4 dBW

Traffic Model	Unit Cost	Low Capacity		Medium Capacity		High Capacity	
		Quantity	Cost	Quantity	Cost	Quantity	Cost
Antenna & LNR	67	26	1742	10	670	211	14137
HPA	41	26	1066	10	410	211	8651
Up-Converter	11	26	286	10	110	211	2321
Down-Converter	11	26	286	10	110	211	2321
Common Equip.-Cent.	340	1	340	1	340	1	340
Common Equip.-Remote	124	25	3100	9	1116	210	26040
Channel Units	2.4	80	192	219	526	1100	2640
Total Ground Segment Subsystem Costs			7012		3282		56450
Annual Ground Segment			2945		1378		23709
Annual Space Segment			172		471		2366
TOTAL ANNUAL COSTS			3117		1849		26075

Modulation System: TDMA
 Satellite Type: DSCS II, Global Beam
 Earth Station G/T: 39 dB/K
 HPA: 1200 W = 30.8 dBW
 System Costs (\$1000)

Table 6-17

Traffic Model	Unit Cost	Low Capacity		Medium Capacity		High Capacity	
		Quantity	Cost	Quantity	Cost	Quantity	Cost
Antenna & LNR	480	26	12480	10	4800	211	101280
HPA	47	26	1217	10	470	211	9917
Up-Converter	14	26	364	10	140	211	2954
Down-Converter	14	26	364	10	140	211	2954
Common Equip.-Cent.	340	1	340	1	340	1	340
Common Equip.-Remote	124	25	3100	9	1116	210	26040
Channel Units	2.4	80	192	219	526	1100	2640
Total Ground Segment Subsystem Costs			18057		7532		146125
Annual Ground Segment			7584		3167		61373
Annual Space Segment			93		255		1279
TOTAL ANNUAL COSTS			7677		3418		62652

Table 6-18
 Modulation System: TDMA
 Satellite Type: DSCS II, Spot Beam
 Earth Station G/T: 24 dB/K
 System Costs
 (\$1000)
 HPA: 630 W = 28 dBW

Traffic Model	Unit Cost	Low Capacity		Medium Capacity		High Capacity	
		Quantity	Cost	Quantity	Cost	Quantity	Cost
Antenna & LNR	47	26	1222	10	470	211	9917
HPA	40	26	1040	10	400	211	8440
Up-Converter	14	26	364	10	140	211	2954
Down-Converter	14	26	364	10	140	211	2954
Common Equip.-Cent.	340	1	340	1	340	1	340
Common Equip.-Remote	124	25	3100	9	1116	210	26040
Channel Units	2.4	80	192	219	526	1100	2640
Total Ground Segment			6622		3132		53285
Subsystem Costs							
Annual Ground Segment			2781		1315		22380
Annual Space Segment			124		340		1705
TOTAL ANNUAL COSTS			2905		1655		24085

Modulation System: TDMA
 Satellite Type: Domsat K-Band
 Earth Station G/T: 34.3 dB/K

Table 6-19
 System Costs
 (\$1000)

HPA: 650 W = 28.1 dBW

Traffic Model	Unit Cost	Low Capacity		Medium Capacity		High Capacity	
		Quantity	Cost	Quantity	Cost	Quantity	Cost
Antenna & INR	66	26	1716	10		211	13926
HPA	42	26	1092	10		211	8862
Up-Converter	14	26	364	10		211	2954
Down-Converter	14	26	364	10		211	2954
Common Equip.-Cent.	340	1	340	1	340	1	340
Common Equip.-Remote	124	25	3100	9	1116	210	26040
Channel Units	2	80	192	219	526	1100	2640
Total Ground Segment Subsystem Costs			7168		3342		57716
Annual Ground Segment			3011		1404		24241
Annual Space Segment			115		314		1577
TOTAL ANNUAL COSTS			3126		1718		25818

6.4 SYSTEMS COSTS WITH TDMA-FDMA TRANSMISSION

In this transmission mode, the TDMA carrier shares transponder bandwidth and power with other services. The transponder TWT operates at a back-off, similar to operation with PSK-FDMA. In this case, the transponder capacity is not adequate to satisfy the high capacity traffic model. System costs are shown in Tables 6-20 through 6-25.

6.5 TDMA WITH REDUCED BIT RATE

Another alternative for TDMA transmission is the reduction of the TDMA bit rate and the use of a full transponder for the system. This permits reduction of antenna size and operation of the transponder at a large back-off; however, the full transponder charge is applied to the system.

The results of this transmission mode are shown in Table 6-26 for the low capacity traffic model and the domestic C-band transponder. This transmission mode is not promising, since the cost savings from reduced antenna and HPA size are less than the extra space segment costs.

Modulation System: TDM-PSK-TDMA-FDMA
 Satellite Type: Domestic, C-Band
 Earth Station G/T: 22 dB/K

Table 6-20
 System Costs
 (\$1000)

HPA: 0.6 W/Ch.

Traffic Model	Unit Cost	Low Capacity		Medium Capacity		High Capacity	
		Quantity	Cost	Quantity	Cost	Quantity	Cost
Antenna & LNR	35	26	910	10	350		
HPA	18	26	468	10	220		
Power dBW	22						
18.8							
21.2							
Up-Converter	11	26	286	10	110		
Down-Converter	11	26	285	10	110		
Common Equip.-Cent.	340	1	340	1	340		
Common Equip.-Remote	124	25	3100	9	1116		
Channel Units	2.4	80	192	219	526		
Total Ground Segment			5582		2772		
Subsystem Costs							
Annual Ground Segment			2344		1164		
Annual Space Segment			461		1262		
TOTAL ANNUAL COSTS			2805		2426		

Modulation System: TDM-PSK-TDMA-FDMA
 Satellite Type: IS IV, Global Beam
 Earth Station G/T: 30 dB/K
 Table 6-21
 System Costs
 (\$1000)
 HPA: 5.4 W/Ch.

Traffic Model	Unit Cost	Low Capacity		Medium Capacity		High Capacity	
		Quantity	Cost	Quantity	Cost	Quantity	Cost
Antenna & LNR	78	26	2028	10			
HPA <u>Power dBW</u>	29	26	754	10			
26.4	36						
30.7							
Up-Converter	11	26	286	10			
Down-Converter	11	26	286	10			
Common Equip.-Cent..	340	1	340	1	340		
Common Equip.-Remote	124	25	3100	9	1116		
Channel Units	2.4	80	192	219	526		
Total Ground Segment Subsystem Costs			6986				
Annual Ground Segment			2934				
Annual Space Segment			1377				
TOTAL ANNUAL COSTS			4311				

Modulation System: TDM-PSK-TDMA-FDMA
 Satellite Type: IS-IVA, Regional
 Earth Station G/T: 26 dB/K

Table 6-22
 System Costs
 (\$1000)

HPA: 2.3 W/Ch.

Traffic Model	Unit Cost	Low Capacity		Medium Capacity		High Capacity	
		Quantity	Cost	Quantity	Cost	Quantity	Cost
Antenna & LNR	50	26	1300	10	500		
<div> <div> Hpa Power dBW </div> <div> 22.6 27.0 </div> </div>	24 29	26	624	10	290		
Up-Converter		26	286	10	110		
Down-Converter		26	286	10	110		
Common Equip.-Cent.	340	1	340	1	340		
Common Equip.-Remote	124	25	3100	9	1116		
Channel Units	2.4	80	192	219	526		
Total Ground Segment Subsystem Costs			6128		2992		
Annual Ground Segment			2574		1257		
Annual Space Segment			923		2524		
TOTAL ANNUAL COSTS			3497		3781		

Modulation System: TDM-PSK-TDMA-FDMA
 Satellite Type: DSCS II, Global Beam
 Earth Station G/T: 30 dB/K
 Table 6-23
 System Costs
 HPA: 1 W/Ch.
 (\$1000)

Traffic Model	Unit Cost	Low Capacity		Medium Capacity		High Capacity	
		Quantity	Cost	Quantity	Cost	Quantity	Cost
Antenna & LNR	66	26	1716	10			
HPA <u>Power dBW</u> 19	20	26	520	10			
Up-Converter	14	26	364	10			
Down-Converter	14	26	364	10			
Common Equip.-Cent.	340	1	340	1	340		
Common Equip.-Remote	124	25	3100	9	1116		
Channel Units	2.4	80	192	219	526		
Total Ground Segment Subsystem Costs			6596				
Annual Ground Segment			2770				
Annual Space Segment			1739				
TOTAL ANNUAL COSTS			4509				

Modulation System: TDM-PSK-TDMA-FDMA
 Satellite Type: DSCS II, Spot Beam
 Earth Station G/T: 22 dB/K
 Table 6-24
 System Costs
 (\$1000)
 HPA: 0.1 W/Ch.

Traffic Model	Unit Cost	Low Capacity		Medium Capacity		High Capacity	
		Quantity	Cost	Quantity	Cost	Quantity	Cost
Antenna & LNR	53	26	1378	10	530		
HPA Power dBW 9.0 13.4	16 18	26	416	10	180		
Up-Converter	14	26	364	10	140		
Down-Converter	14	26	364	10	140		
Common Equip.-Cent.	340	1	340	1	340		
Common Equip.-Remote	124	25	3100	9	1116		
Channel Units	2.4	80	192	219	526		
Total Ground Segment Subsystem Costs			6154		2972		
Annual Ground Segment			2585		1248		
Annual Space Segment			463		1266		
TOTAL ANNUAL COSTS			3048		2514		

Modulation System: TDM-PSK-TDMA-FDMA
 Satellite Type: Domestic, K-Band
 Earth Station G/T: 28 dB/K
 Table 6-25
 System Costs
 (\$1000)
 HPA: 0.2 W/Ch.

Traffic Model	Unit Cost	Low Capacity		Medium Capacity		High Capacity	
		Quantity	Cost	Quantity	Cost	Quantity	Cost
Antenna & LNR	51	26	1326	10			
HPA $\frac{\text{Power dBW}}{12}$	18	26	468	10			
Up-Converter	14	26	364	10			
Down-Converter	14	26	364	10			
Common Equip.-Cent.	340	1	340	1	340		
Common Equip.-Remote	124	25	3100	9	1116		
Channel Units	2.4	80	192	219	526		
Total Ground Segment Subsystem Costs			6154				
Annual Ground Segment			2585				
Annual Space Segment			1304				
TOTAL ANNUAL COSTS			3889				

Table 6-26
System Costs
(\$1000)

Modulation System: TDMA - Reduced Rate
Satellite Type: Domestic C-Band
Earth Station G/T: 20 dB/K

Traffic Model	Unit Cost	Low Capacity		Medium Capacity		High Capacity	
		Quantity	Cost	Quantity	Cost	Quantity	Cost
Antenna & LNR	30	26	780				
HPA 19.6 dBW	20	26	520				
Up-Converter	11	26	286				
Down-Converter	11	26	286				
Common Equip.-Cent.	340	1	340				
Common Equip.-Remote	124	25	3100				
Channel Units	2.4	80	192				
Total Ground Segment Subsystem Costs			5504				
Annual Ground Segment			2312				
Annual Space Segment			2000				
TOTAL ANNUAL COSTS			4312				

6.6 COST COMPARISON

Tables 6-27 through 6-29 show the summary of annual systems costs of all cases that have been investigated. PSK-SCPC transmission is always accomplished at the lowest systems cost.

Table 6-30 shows a cost comparison for the different modulation techniques, based on average systems costs for all satellite types considered.

Table 6-31 is a normalized systems operation based on the average costs of Table 6-30.

Table 6-27
Systems Cost Comparison
Low Capacity Model
Annual Costs (\$1000)

Modulation System	PSK-SCPC	TDM-PSK-FDMA	TDMA Max. Bit Rate	TDMA-FDMA	TDMA Reduced Rate
DSCS II, Global Beam	1786	5184	7677	5409	
DSCS II, Spot Beam	1267	4721	2905	3048	
Domestic, C-Band	1111	4204	2682	2805	4312
Domestic, K-Band	1346	4894	3126	3889	
INTELSAT IV, Global	1524	4965	8294	4311	
INTELSAT IV-A, Regional	1269	4505	3117	3497	
Average	1384	4746	4633	3826	4312

Table 6-28
Systems Cost Comparison
Medium Capacity Model
Annual Costs (\$1000)

Modulation System	PSK-SCPC	TDM-PSK-FDMA	TDMA Max. Bit Rate	TDMA-FDMA	TDMA Reduced Rate
DSCS II, Global Beam	2085	3839	3418		
DSCS II, Spot Beam	1294	2860	1655	2514	
Domestic, C-Band	1146	2576	1479	2426	
Domestic, K-Band	1692	3419	1718		
INTELSAT IV, Global	1818	3500	3738		
INTELSAT IV-A, Regional	1484	2712	1849	3781	
Average	1590	3150	2310	2907	

Table 6-29
Systems Cost Comparison
High Capacity Model
Annual Costs (\$1000)

Modulation System	PSK-SCPC	TDM-PSK-FDMA	TDMA Max. Bit Rate	TDMA-FDMA	TDMA Reduced Rate
DSCS II, Global Beam	17022	54195	62652		
DSCS II, Spot Beam	11809		24085		
Domestic, C-Band	10339		22056		
Domestic, K-Band	13241		25818		
INTELSAT IV, Global	14737	54195	67843		
INTELSAT IV-A, Regional	12164		26075		
Average	13220	54195	38088		

Table 6-30
Averaged Systems Cost Comparison
Annual Costs (\$1000)

Traffic Model	Low Capacity	Medium Capacity	High Capacity
PSK-SCPC	1384	1590	13220
TDM-PSK-FDMA	4746	3150	54195
TDMA-Max. Bit Rate	4633	2310	38088
TDMA-FDMA	3826	2907	
TDMA-Reduced Rate	4312		

Table 6-31
Normalized Systems Cost Comparison
Annual Costs, PSK-SCPC = 1.00

Traffic Model	Low Capacity	Medium Capacity	High Capacity	Average
PSK-SCPC	1.00	1.00	1.00	1.00
TDM-PSK-FDMA	3.43	1.98	4.10	3.03
TDM-Max. Bit Rate	3.35	1.45	2.88	2.41
TDMA-FDMA	2.76	1.83		2.25
TDMA-Reduced Rate	3.14			3.14

Section 7
GENERAL COST COMPARISON

General cost models have been generated to permit determination of the break-even channel capacity for PSK-SCPC versus TDMA transmission. It was found that the TDM-PSK-FDMA transmission technique results in higher costs than SCPC or TDMA transmission, in addition to providing only limited interconnectivity. The TDM-PSK-FDMA technique has therefore been eliminated from further consideration.

7.1 GENERAL PSK-SCPC COST MODEL

Based on the work presented in preceding sections, the PSK-SCPC systems costs can be approximated by the following relationship:

$$A = [C_1 + (C_2 + C_3 + C_4 + C_5)m + (C_6 + C_7)n]a + \frac{A_1}{x} \cdot \frac{n}{1.5}$$

where:

- A = total annual systems costs
- C₁ = central station common equipment cost minus remote station common equipment cost
- C₂ = cost of antenna and LNR
- C₃ = fixed portion of HPA cost
- C₄ = cost of up- and down- converter
- C₅ = cost of remote station common equipment
- m = number of earth stations in the system
- C₆ = cost of channel equipment, per channel
- C₇ = variable cost of HPA, per channel
- A₁ = annual transponder lease cost
- x = transponder channel capacity

n = number of channel units in the system. for SCPC
 it is assumed that the number of space segment
 channels is $\frac{n}{1.5}$
 a = annualizing factor

The above equation may be rearranged to consist of three terms: A fixed term, a term proportional to the number of earth stations in the system and a term proportional to the number of channels in the system.

$$A = aC_1 + ma(C_2 + C_3 + C_4 + C_5) + n \left[a(C_6 + C_7) + \frac{A_1}{1.5x} \right]$$

Earth station HPA costs were found to have only a minor impact on the total systems costs. For this reason, they will be approximated by a fixed term for each earth station and a variable term depending on the total number of channels in the system. The result is within the accuracy of the assumptions.

The following terms depend on the specific satellite type selected: C_2 , C_3 , C_4 , A_1 and x . The applicable numbers have been listed in Table 7-1.

With PSK-SCPC, the required space segment capacity is lower than the number of channel units. This relationship is shown in Section 5.1.1 for the three traffic models. For these general calculations, a concentration factor of 1.5 has been used. The space segment cost term is reduced by this factor in the above equations.

Table 7-1
Input Values for General Cost Calculations for PSK-SCPC Transmission

Costs in \$1000						
	DSCS II Global	DSCS II Spot	Domestic C-Band	Domestic K-Band*	IS IV Global	IS IV-A Regional
C ₁	93	93	93	93	93	93
C ₂	65	34	30	42	50	35
C ₃	26	18	15	14	27	22
C ₄	28	28	22	28	22	22
C ₅	12	12	12	12	12	12
C ₆	6	6	6	6	6	6
C ₇	0.4	0.3	0.2	0.2	0.4	0.3
A ₁	3000	4000	2000	4000	3000	4000
x	490	2000	1440	2160	617	1230

*The G/T was increased from 24 to 28 dB/K to reduce space segment costs. The resulting increase of antenna cost was \$8k, the reduction in HPA cost was \$4k. The increase in transponder capacity was from 871 to 2,160 channels.

Using the values of Table 7-1, the relationships shown in Table 7-2 have been developed:

Table 7-2
Annual Cost Formulas for PSK-SCPC Transmission

Satellite Type	Annual Costs in \$1000
DSCS II, Global Beam	$A = 39.1 + 55.0m + 6.8n$
DSCS II, Spot Beam	$A = 39.1 + 38.6m + 4.0n$
Domestic, C-Band	$A = 39.1 + 33.2m + 3.5n$
Domestic, K-Band	$A = 39.1 + 40.3m + 3.8n$
INTELSAT IV, Global Beam	$A = 39.1 + 46.6m + 5.9n$
INTELSAT IV-A, Regional	$A = 39.1 + 38.2m + 4.8n$

7.2 GENERAL TDMA COST MODEL

In this model, it is assumed that the system operates at the maximum transponder bit rate that is possible within 16 kbps delta modulation and 2 phase PSK. The time frame is shared with other services and only that portion of the time

required to meet the traffic model is charged to the TDMA systems costs.

$$A' = [C'_1 + (C'_2 + C'_3 + C'_4 + C'_5)m + nC'_6]a + \frac{A_1}{x'} \cdot n$$

The same terminology applies as in Section 7.1, but the TDMA quantities are designated as "prime" (e.g. A'). Again, this equation is rearranged into a fixed term, a term proportional to the number of earth stations in the system and a term proportional to the number of channels in the system. All HPAs must operate at the maximum bit rate, therefore, there is no channel dependent term for HPA costs in the above expression.

$$A' = aC'_1 + ma[C'_2 + C'_3 + C'_4 + C'_5] + n \left[aC'_6 + \frac{A_1}{x'} \right]$$

Cost values applicable to the TDMA system are shown in Table 7-3.

Table 7-3
Input Values for General Cost Calculations for TDMA Transmission
(\$1000)

	DSCS II Global	DSCS II Spot	Domestic C-Band	Domestic K-Band	IS IV Global	IS IV-A Regional
C ₁	216	216	216	216	216	216
C ₂	480	47	46	66	554	67
C ₃	47	40	30	42	32	41
C ₄	28	28	22	28	22	22
C ₅	124	124	124	124	124	124
C ₆	2.4	2.4	2.4	2.4	2.4	2.4
A ₁	3000	4000	2000	4000	3000	4000
x'	2580	2580	1860	2790	1860	1860

The resulting annual cost formulas are shown in Table 7-4.

Table 7-4
Annual Cost Formulas for TDMA Transmission

Satellite Type	Annual Costs in \$1000
DSCS II, Global Beam	$A' = 90.7 + 285.2m + 2.2n$
DSCS II, Spot Beam	$A' = 90.7 + 100.4m + 2.6n$
Domestic, C-Band	$A' = 90.7 + 92.4m + 2.1n$
Domestic, K-Band	$A' = 90.7 + 109.2m + 2.4n$
INTELSAT IV, Global Beam	$A' = 90.7 + 307.4m + 2.6n$
INTELSAT IV-A, Regional	$A' = 90.7 + 106.7m + 3.2n$

7.3 CALCULATION OF BREAK-EVEN POINT

The break-even point for PSK-SCPC transmission and TDMA transmission has been calculated based on the formulas in Tables 7-2 and 7-4. The break-even formulas are shown in Table 7-5.

Table 7-5
Break-Even Formulas

Satellite Type	Break-Even Channel Capacity (Channel Units per System)
DSCS II, Global Beam	$n = 11 + 50m$
DSCS II, Spot Beam	$n = 37 + 44m$
Domestic, C-Band	$n = 37 + 42m$
Domestic, K-Band	$n = 37 + 49m$
INTELSAT IV, Global Beam	$n = 16 + 79m$
INTELSAT IV-A, Regional	$n = 32 + 43m$
Average	$n = 30 + 50m$

Average break-even capacities are shown in Table 7-6.

Table 7-6
Average Break-Even Capacities

Number of Earth Stations Per System	Number of Channel Units Per System	Number of Channel Units Per Earth Station
3	180	60
5	280	56
10	530	53
100	5,030	50

7.4 GENERALIZED CALCULATION OF COST DIFFERENCE

A generalized calculation of cost difference between SCPC systems and TDMA systems is given below for the three satellite types. It will be noted that the cost differences are similar for the systems working with spot beam transponders as a group and are also similar for those systems working with the two global beam transponders. Average formulas have therefore been generated, covering the case of spot beam and global beam transponders.

Table 7-7
Cost Difference Formulas
Annual Cost Difference in \$1000

Transponder Type	Cost Difference: $A' - A$ TDMA Minus SCPC System Costs
DSCS II, Global Beam	$A' - A = 52 + 230m - 4.6n$
INTELSAT IV, Global Beam	$A' - A = 52 + 261m - 3.3n$
Average Global Beam Transponder	$A' - A = 52 + 246m - 4.0n$
DSCS II, Spot Beam	$A' - A = 52 + 62m - 1.4n$
Domestic, C-Band	$A' - A = 52 + 60m - 1.4n$
Domestic, K-Band	$A' - A = 52 + 69m - 1.4n$
INTELSAT IV-A, Regional	$A' - A = 52 + 69m - 1.6n$
Average Spot Beam Transponder	$A' - A = 52 + 65m - 1.5n$

Figures 7-1 and 7-2 are graphs of cost differences calculated for systems operating with an average global beam or spot beam transponder. In the upper portion of the graphs, the SCPC systems are cheaper; in the lower portion the TDMA systems are cheaper.

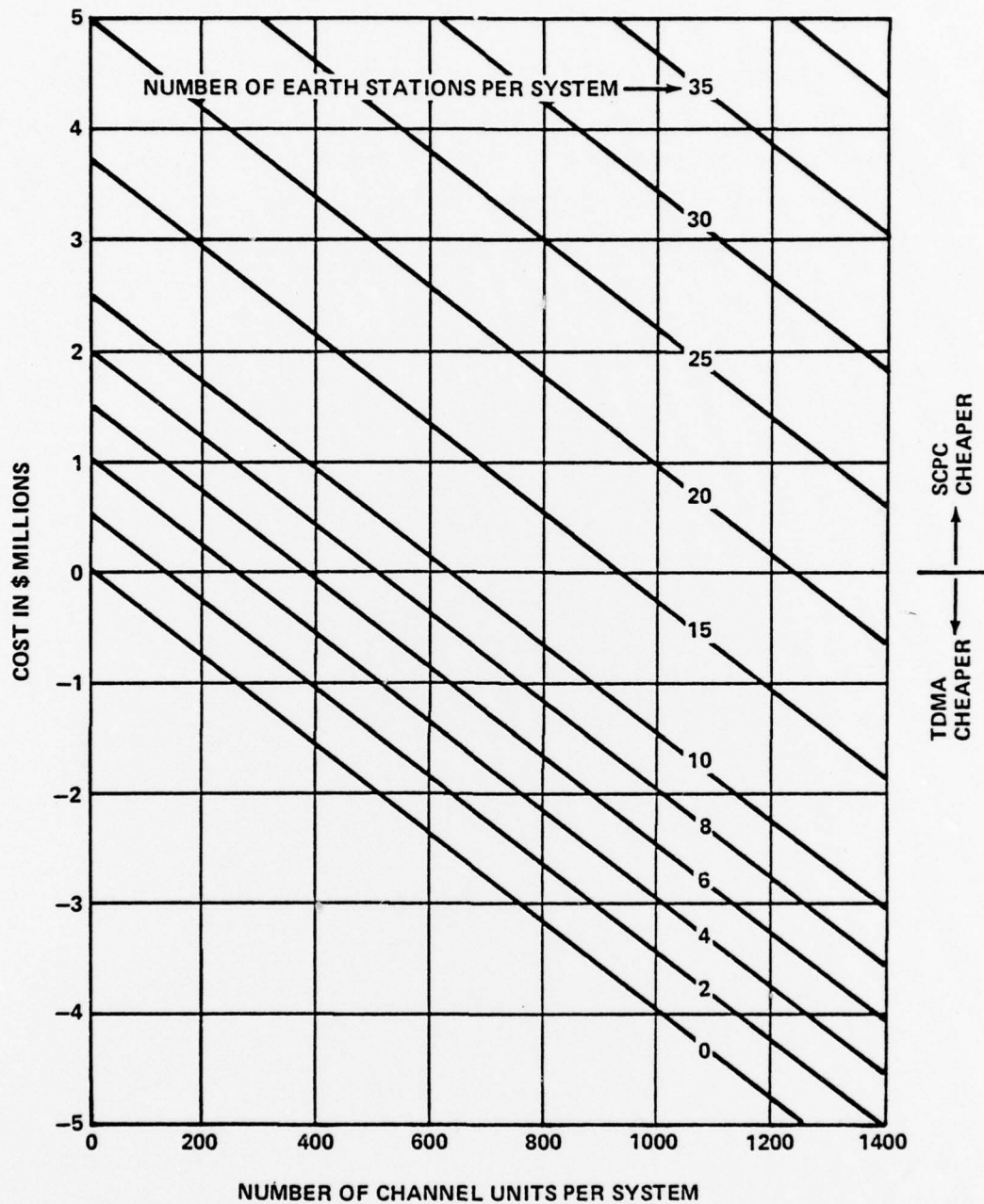


FIGURE 7-1

ANNUAL COST DIFFERENCE IN \$ MILLION
TDMA SYSTEM COSTS MINUS SCPC
SYSTEM COSTS FOR OPERATION WITH
A TYPICAL GLOBAL BEAM TRANSPONDER

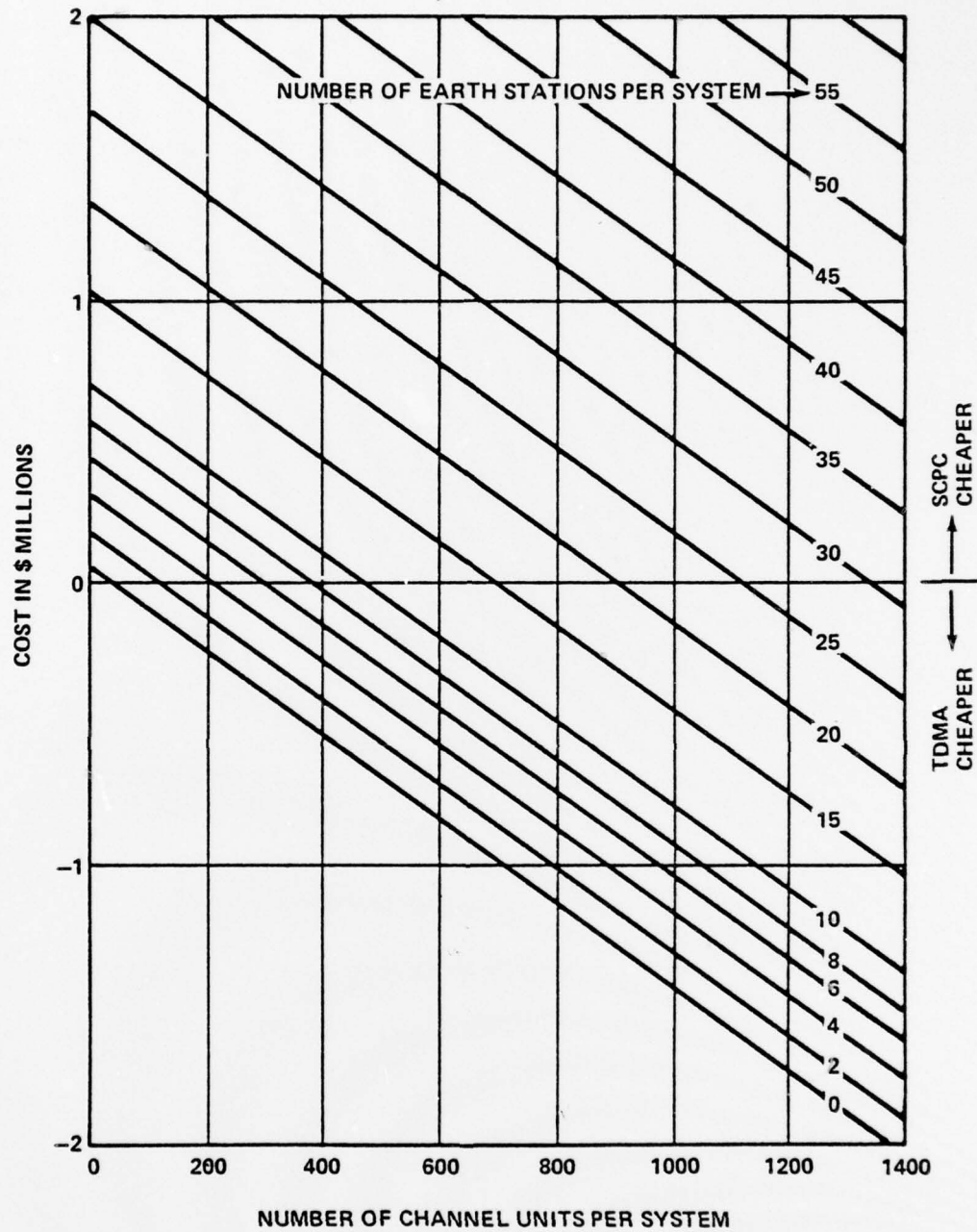


FIGURE 7-2
ANNUAL COST DIFFERENCE IN \$ MILLION
TDMA SYSTEM COSTS MINUS SCPC
SYSTEM COSTS FOR OPERATION WITH
A TYPICAL SPOT BEAM TRANSPONDER

Section 8
SENSITIVITY STUDY

In this Section, the sensitivity of the study results to the assumptions has been examined.

8.1 SENSITIVITY TO EARTH STATION COST VARIATIONS

Earth station cost can vary widely, depending on the type of specifications, quantities of equipment procured and location of installation. For this reason, it is interesting to investigate the sensitivity of the study results to changes in the cost assumptions.

Section 4.2.6 shows that digital baseband equipment procured to Mil Specs costs about twice as much as commercial equipment. It was assumed that the same cost ratio also applies for all other earth station equipment and the break-even capacities were calculated on this basis. The comparison of the results with those for commercial equipment is shown in Table 8-1.

Table 8-1
COMPARISON OF BREAK-EVEN CAPACITIES
(number of channel units in the system)

Transponder Type	Break-Even Capacity With Mil Spec Equip.	Break-Even Capacity With Commercial Equip.
DSCS II, Global Beam	$n = 16 + 73m$	$n = 11 + 50m$
DSCS II, Spot Beam	$n = 34 + 41m$	$n = 37 + 44m$
Domestic, C-Band	$n = 34 + 40m$	$n = 37 + 42m$
Domestic, K-Band	$n = 28 + 37m$	$n = 37 + 49m$
INTELSAT IV, Global Beam	$n = 21 + 104m$	$n = 16 + 79m$
INTELSAT IV-A, Regional	$n = 31 + 42m$	$n = 32 + 43m$
Average	$n = 27 + 56m$	$n = 30 + 50m$

In this comparison, it was found that with Mil Spec equipment the break-even capacities for operation with global beam transponders increase by about 25 channels per earth station and that the break-even capacities for operation with spot beam transponders remain about the same. As the result the average break-even capacity for all transponders considered increased by about 10%.

8.2 SENSITIVITY TO SPACE SEGMENT COST VARIATIONS

The study uses 6 different transponders with transponder lease rates varying from \$2 Million to \$4 Million per year. Thus, the results already take into account the above range of transponder space segment cost variations.

In this section, the break-even capacities have been calculated, based on the assumption that space segment would be available free of charge to the system's user. The equipment cost base was kept at Mil Spec equipment level. The break-even capacity increased further to about 140 channels per earth station. This is to be expected, since the per channel space segment requirement for global beam operation is much higher than for spot beam operation. The results are shown in Table 8-2.

Table 8-2
BREAK-EVEN CAPACITIES IN THE ABSENCE
OF SPACE SEGMENT CHARGES

Transponder Type	Break-Even Capacity With Mil Spec Equipment
DSCS II, Global Beam	$n = 30 + 135m$
DSCS II, Spot Beam	$n = 31 + 38m$
Domestic, C-Band	$n = 32 + 37m$
Domestic, K-Band	$n = 32 + 43m$
INTELSAT IV, Global Beam	$n = 30 + 153m$
INTELSAT IV-A, Regional	$n = 31 + 42m$
Average	$n = 31 + 75m$

8.3 BREAK-EVEN CAPACITIES WITH BASEBAND EQUIPMENT COSTS ONLY

In this Section, the break-even capacities are calculated, taking into account only baseband equipment costs.

$$C = C_1 + mC_5 + nC_6$$

$$C = C'$$

$$n = \frac{[C_1 - C_1] + m[C'_5 - C_5]}{[C'_6 - C_6]}$$

$$n = 34 + 31m$$

Thus, the costs of the baseband equipment alone lead to a break-even capacity of over 30 channels per earth station. The RF equipment costs further increase the break-even capacity.

8.4 TDMA SYSTEMS WITH FULLY VARIABLE DEMAND ASSIGNMENT

In such systems the burst length of each earth station is adjusted in accordance with its instantaneous traffic requirement. The cost of a non-redundant terminal is estimated to be \$250K, compared with \$124K for equipment with only variable destination demand assignment.

The increase of annual cost due to the more extensive TDMA equipment can be compared with the cost saving resulting from space segment cost reduction. The highest cost per channel for all transponders considered, namely that of INTELSAT IV-A, was used. The cost per channel for the six transponder types is shown below.

Transponder Type	Annual Lease* Cost (\$1000)	Transponder** Capacity	Annual Space Segment Cost Per Channel (\$1000)
INTELSAT IV, Global	3000	1860	1.61
INTELSAT IV-A, Regional	4000	1860	2.15
Domestic, C-Band	2000	1860	1.08
Domestic, K-Band	4000	2790	1.43
DSCS II, Global Beam	3000	2580	1.16
DSCS II, Spot Beam	4000	4000	1.55

* From Table 4-1

** From Table 5-24

The cost reduction due to fewer space segment channels required with fully variable demand assigned TDMA is shown below for the three Traffic Models.

SPACE SEGMENT COST SAVINGS

Traffic Model	Number of Channels* Variable Destination	Space Seg. with Full Demand Assignment	Difference Number of Channels	Annual Cost Saving for IS IV-A, \$1000
Low Capacity	80	29	51	110
Medium Capacity	219	152	67	144
High Capacity	1100	518	582	1251

*From executive summary

The increased ground segment cost for fully variable demand assigned TDMA equipment for the three traffic models is shown below. A cost difference of \$126k in investment cost applies to each remote ground station, and twice that amount to the central station. An annualizing factor of 0.42 is used, as explained in section 6.1.

GROUND SEGMENT COST INCREASE

Traffic Model	Number of Terminals	Annual Cost Difference in \$1000
Low Capacity	27	1,429
Medium Capacity	11	582
High Capacity	212	11,219

Thus, the ground segment cost increase exceeds the space segment cost saving by a large factor in all cases.